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SULPHUR EXTRACTION FROM LOW GRADE ORES

by



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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled SULPHUR EXTRACTION FROM LOW GRADE ORES, submitted by John Hildred in partial fulfilment of the requirements for the degree of Master of Science in Chemical Engineering.

ABSTRACT

A native sulphur bearing surface ore deposit occurs in northern Alberta of sufficient quality to warrant feasibility studies into the economic aspects of recovery of the brimstone values. A simple processing scheme is desirable since the deposit is located in a remote area.

Experimental work, using a synthetic ore, has shown that a solvent extraction approach meets this simplicity concept. The use of kerosene, on account of its availability and cheapness as the sulphur solvent, is demonstrated. High purity sulphur can be produced by this method but solvent losses in the ore wastes are excessive.

The profitability of this route was examined with the aid of a computer simulation model. The optimum processing conditions established yielding the lowest operating costs show that, for a plant producing 200 tons per day of 99.5% pure sulphur, an estimated production cost of \$19.68 per ton is incurred. With the currently depressed market it is concluded that manufacturing sulphur by this method would not prove to be a profitable venture.

It is suggested that further work be suspended until such time as the market situation improves. Any future investigations should be undertaken on the Alberta ore and include a study into the reduction of the solvent losses.

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CHAPTER I

INTRODUCTION

Traditionally much of the world's elemental sulphur has been produced by the Frasch Process (37)(38) from the so-called "salt domes" situated on the Gulf Coasts of Texas and Louisiana (71)(42). Faced with the depletion of these reserves, brimstone manufacturers have been actively examining other sulphur bearing materials for profitable exploitation. Consequently they have devised several processing techniques to handle a wide variety of raw materials such as smelter off-gases rich in sulphur dioxide, gypsum, hydrogen sulphide from the purification of natural gases and native sulphur-bearing ore deposits of volcanic or sedimentary origin.

Ore deposits constitute a significant proportion of the known brimstone reserves and occur in numerous parts of the world, either in widely scattered outcrops or concentrated veins. Many of these ore bodies are of insufficient grade or quantity to be profitably workable. Nevertheless, in the Fort Vermilion-Fort McMurray region of northern Alberta (2)(7)(60) an elemental sulphur surface deposit has been found of high enough quality to warrant further study.

The sulphur, in this ore body, is believed (60) to have been formed by bacterial action on gypsum strata located beneath the earth's surface and then brought to the surface by circulating meteoric waters. Oxidation of gaseous hydrogen sulphide, also produced in this biogenic process, may be responsible also for some of the deposited sulphur.

Thus the deposit principally contains native sulphur, in widely varying proportions, and gypsum, together with small amounts of fragmented calcite, all of which combine to give the material a yellowish soil-like appearance. As it occurs mainly in close proximity to springs and streams, this ore naturally contains a high quantity of moisture, sometimes making it quite muddy in consistency.

Up to 1968, brimstone had been in short supply for a considerable period resulting in its price rising to about \$35.00 per ton (16). Because of this market situation, work was started to investigate the feasibility of recovering the sulphur from the Alberta ore.

Since this is a surface ore, it is not amenable to processing by the Frasch Method which requires an environment able to withstand high pressures i.e. the sulphur must occur deep in the ground. Therefore an alternative beneficiation technique is desirable. For ore bodies solvent extraction, sublimation of the sulphur and hot water autoclaving represent some of the approaches that have been developed. It is possible that one of these methods can be adapted to process this ore.

As the ore body occurs in a remote location any production facility, at best, should comprise the simplest handling equipment. Resort to a continuous low pressure and temperature processing route is indicated, thus eliminating the use of steam and expensive coded pressure vessels. This concept will form the basic design philosophy of any unit proposed for construction in the area.

The aim of this study is, then, to develop a process for the

recovery of sulphur contained in the surface ore body. Such a process must be competitive with other methods but remain within the confines of the design philosophy and peculiarities of the raw material itself. Preferably the sulphur will be produced in its elemental form, rather than as sulphur dioxide or sulphuric acid. This will minimise marketing problems and expenses.

CHAPTER II

LITERATURE SURVEY

Introduction

This survey outlines methods of brimstone recovery from native ore bodies which cannot be processed by the Frasch technique. The drawbacks of each method arising from design philosophy considerations are also discussed.

Thermal Methods

Because sulphur boils at 832°F and is readily evolved from an ore matrix, vaporisation followed by condensation offers one way of recovery provided the high energy requirement can be met cheaply enough. As the ore body is situated near plentiful fuel supplies, a plant located at the deposit utilising this route would, at first sight, appear to be most promising.

One of the simplest methods examined (33) uses the fluidised bed principle which is suited to continuous operation and provides good thermal characteristics. Briefly, this process treats crushed ore, which constitutes the bed solids, in a bed fluidised by hot air. The bed temperature is maintained well above the boiling point of sulphur so that the formation of highly viscous, poorly heat conductive liquid sulphur is minimised. This is achieved by rapid transfer of heat to the incoming feed. Once the sulphur has been vaporised the gas stream passes to a cyclone for dust removal prior to entering a condenser. Here the liquid sulphur product is withdrawn. The sulphur free gases

are then partly recycled, to effect heat economy, and partly vented. The spent ore or gangue is discharged from the bed directly for disposal.

The bed operating temperature is obtained by burning some of the sulphur contained in the ore with air during fluidisation. Not only is this procedure wasteful in sulphur values, it also unnecessarily creates sulphur dioxide which when vented causes serious atmospheric pollution; there being no vent-gas cleaning facilities specified for the plant. One way of overcoming this problem, although suggested in the article but not elaborated upon, is to use flue gases as the heating and fluidising media. However these gases may still contain sufficient oxygen, due to incomplete combustion, to enable sulphur dioxide to form. Another reason against the use of air is the severe explosion hazard resulting from excessive dusting caused by particle attrition in the bed.

Hartley et al (40), in their process employing a raked hearth furnace, describe the use of flue gases, as the heating media, directly in contact with the ore. The sulphur laden gases are then passed to a condenser for sulphur recovery. Again the problem of atmospheric pollution arises. With this approach the complexities of the mechanical rake drive and the air cooling system for the rake arms are also apparent.

Thus it can be seen that directly heated ore charges are not advisable in view of sulphur dioxide formation. An indirectly heated process has been presented by Dale (30) who recommends heated pebbles in direct contact with the raw materials contained in an externally

heated paddle trough conveyor as the most satisfactory method. Potential operating troubles can be envisaged with the extensive amount of mechanical handling equipment specified, i.e. conveyor air locks, screens to separate the pebbles from the waste products, and a pebble elevator for loading the pebble heater. The formation of ore agglomerates, caused by adhesion of viscous molten sulphur covered particles, resulting from low heating rates are also a distinct possibility.

One of the major disadvantages of the above processes is dust carry-over contaminating the product. Dusting is excessive under all except quiescent conditions and still causes serious problems (51) although a cyclone is claimed by Hartley to be satisfactory in reducing contamination. At present, the only effective way appears to be filtering the molten sulphur(72) immediately it leaves the condenser.

Another problematical aspect of this route is the operation of the sulphur condenser. It has been experienced, notably in Claus Process operations, that not all of the sulphur will be condensed. Some of it will escape to the atmosphere as a mist. Such escapes serve to reduce the sulphur recovery and create undesirable atmospheric contaminants. Blockages caused by the brimstone solidifying are also commonplace.

To summarise the thermal routes are not suitable for processing the Alberta material. They require sophisticated machinery and cause atmospheric pollution. In addition product purity may be below specification due to dust carry-over, without further treatment. On heating the Alberta ore, because of its soil-like nature, any organic

matter present will decompose adding further purity problems. On closer examination, the reported vaporisation methods conflict not only with the need for simple equipment but also governmental pollution standards. Therefore they are not recommended for further study.

Melting Techniques

An alternative way of employing a sulphur phase change to recover sulphur values from an ore is to melt the brimstone particles by indirect heating and allow them to agglomerate and drain from the gangue solids. This method does not require as much heat as the vaporisation routes and should be more attractive since production costs ought to be substantially less. This approach has been tried on several occasions (51)(56) but experience has shown that only part of the brimstone drains away, the remainder being held in the ore interstices. Also any solid fines present in the feed tended to contaminate the liquid product without further purification. Thus recovery and product purity were low and the heat utilisation poor since none could usefully be recovered from the gangue or product.

A more successful approach has been an adaptation of the Frasch Process. The ore is treated in a heated liquid media at a temperature just above the melting point of sulphur. The molten product is then separated from the ore wastes and sent to storage. In fact, most of the processes developed use hot water as the heating fluid. In order to attain the desired temperature, without causing the water to boil, a pressure of about 35 p.s.i.g. is needed.

Probably the most successful process devised is the one offered

by the Chemical Construction Corporation (23)(36)(56). Essentially the operation consists of crushing and grinding the ore to -28 mesh size and forming a slurry of about 25% wt. solids with hot water. The slurry is pumped into a special autoclave, preferably a stainless steel coil. Here steam at 50 p.s.i.g. is introduced to supply the necessary heat for melting the sulphur. The function of the coil is to provide extremely turbulent flow conditions thus aiding the melting and agglomeration of the sulphur particles. The hot mixture containing water, liquid sulphur and gangue is then cooled rapidly by cold water injection prior to separation of the resulting solid brimstone spheres by flotation. Finally the flotation concentrates are melted, again using steam, and filtered before being sent to a storage pit. As large quantities of hot water form an important part of this recovery operation, recycling the water overflows from thickeners handling the flotation stage tailings is carried out. This conserves not only water but heat as well, significantly reducing manufacturing costs. Brimstone recovery is claimed to be above 90% with a purity of 99.5% or better.

Another process outlined by Benz (15) employs the same steps as above but uses different and more complex process machinery.

McGauley, in two patents (57)(58), describes a hot water method in which concentration of the agglomerated sulphur particles by flotation and the subsequent remelting and filtering steps are eliminated. In his process the crushed and ground native sulphur bearing material is slurried with hot water and heated with steam under

pressure as before. The mixture of water, liquid sulphur and gangue is then transferred to a centrifuge where the solids are removed. The water and sulphur are passed to a separating tank, the water being recycled to the centrifuge to improve the washing of the molten sulphur from the tailings and to the slurry mixing tank. Once the centrifuge is full of solid wastes, the feed is stopped and its basket emptied after a final water wash and drying operation.

The second patent discusses an improvement to the method so that ores containing clay-like or colloidal fines in addition to the more common ones of volcanic origin can be treated. It had been observed in the centrifuging operation that unless these fines were removed before this stage, the gangue solids became impervious to drainage and thus some product was lost. Fines removal is claimed to be effective if immediately prior to centrifuging the three phase mixture is introduced tangentially into a separating tank thereby imparting a swirling motion to the materials. The fines will then preferentially concentrate in the water layer and can be easily disposed.

Still another technique (47) uses a water slurry initially but heats it at high pressure (about 200 p.s.i.g.) to a temperature above the boiling point of sulphur so that a dispersion of ore solids in a vapour media is created. The highly turbulent flow conditions created result in the attrition of the raw materials so that the sulphur is exposed and more easily released. The sulphur-free waste is separated cyclonically and the gases cooled in a partial condenser to yield molten sulphur. Steam from this condenser then passes to the feed

slurry preheater and the condensate formed provides the water needed for making the slurry. Comparing this method to the others already discussed, it is apparent that the unnecessary heating of the ore above the melting point of sulphur with the corresponding need for high pressures results in higher manufacturing costs. Thus the use of high operating pressures renders this route unacceptable for processing the Alberta ore and therefore will not be further studied.

One of the reasons aiding the development of the hot water route is that the high surface tension of liquid sulphur tends to prevent it from wetting the gangue, in the presence of water. This reduces the amount of sulphur retained in the solid pores which would otherwise become unrecoverable. However, Lewis and Tisdell (51) report that brimstone retention on the gangue continues to be troublesome although handling improvements have reduced this to a more tolerable level.

Other melting methods that have been tried have used calcium chloride solutions (1)(19), zinc chloride solutions (13) and 98% sulphuric acid (23)(36) as the heating fluid. As these liquids boil at temperatures above the melting point of sulphur the separation was undertaken at atmospheric pressure. Hence pressure vessels were not required. However these approaches necessitated corrosion resistant materials (35) and have not been found as tractable as the hot water route.

A major disadvantage of any melting approach, whether it is on a batch basis as practised in Chile (14)(40) or on a continuous

basis like the Chemico Process, is the need for equipment that will be corrosion resistant. The process vessels must be resistant not only to, say, hot water but also sulphur dioxide and hydrogen sulphide which are formed in small amounts. This inevitably requires stainless steel pipework and lead and acid proof vessel linings which, of course, adds significantly to the initial capital expenditure required. This fact together with the extensive use of steam and resulting elevated pressures, does not meet the design requirements and therefore this method cannot be advised for a unit proposed for construction in northern Alberta.

Froth Flotation Methods

As indicated in the previous section, froth flotation is used to concentrate agglomerated brimstone particles before finally filtering to achieve the desired product purity. With this in mind, flotation as a beneficiation method has been examined for its suitability as the major step in a recovery route.

All the relevant papers reviewed (14)(41)(49) suggest froth flotation is satisfactory as the primary beneficiation stage. Filtration of the concentrates must be included as a final step to yield a marketable product other than that suitable as a soil conditioner.

To prepare the ore in a suitable form for floating, fine grinding to -200 mesh size is necessary to release the sulphur particles. However even then microscopic studies (36) have shown a large amount of the sulphur is still bonded to the gangue. Bonding, as well as occurring naturally, can be caused by the grinding operation melting

the sulphur particles by friction heating and allowing them to agglomerate. This tends to produce a material that is not as manageable as it was originally.

Fine grinding normally results in much of the brimstone reporting as fines in the feed material. Though sulphur is considered to be a natural floater, it will, when present as fines, tend to stabilise the froth bubbles. The selectivity of the process is therefore reduced and consequently the sulphur content of the concentrate is lowered.

The floating of the sulphur is usually carried out in an aqueous media in the presence of an alcohol frothing agent such as methyl isobutyl carbinol. It is used either alone or with kerosene acting as a collector and trisodium pyrophosphate as a dispersant. Normally the collected concentrate assays between 75% and 80% sulphur by weight and contains 90% of the original sulphur present in the feed. Because of contamination by gangue fines a final melting and filtration stage is required to produce on-grade brimstone. Usually steam has been employed in the melting operation.

Another of the problems associated with grinding is the explosion hazard due to dust formation. Also from an operational aspect the power consumption for grinding becomes excessive with the decreasing particle size required. An economic compromise must therefore be made between the particle size produced and the grinding costs.

Tests on the Alberta ore (50) have shown flotation will produce an enriched concentrate but as is usually experienced the grade failed to meet acceptable purity standards. Lewis and Tisdell (51) and

Bradley (17) have pointed out that flotation may offer considerable monetary savings in any process that can operate on flotation concentrate material. This is the case in some Chilean operations (14). Whilst froth flotation has been proved not to produce brimstone of a purity satisfactory to most consumers in one step, its incorporation in a manufacturing route, if economically viable, is a distinct possibility.

Solvent Extraction Methods

As outlined in the introductory remarks, solvent extraction offers another method of brimstone recovery. Briefly, solvent extraction consists of dissolving the sulphur content of an ore in a suitable solvent at elevated temperatures and separating the solid wastes from the now sulphur rich solvent. The temperature of the solution is then lowered so that the change in solubility will cause the brimstone to precipitate out of solution. Recovery of the solvent from the tailings and product for reuse by washing, vaporisation or filtration completes the operation. Discussion relating to this route can be found in several patents and literature articles covering the application of many different solvents. Figure 1 illustrates this process diagrammatically.

Gas oil, for example, has been used as the extraction agent in an experimental batch process described by Ekonomopoulos (35) in which ore is treated at a temperature in excess of the sulphur melting point. Such a temperature is advised because it is claimed that sulphur, in its liquid state, is more readily soluble than in the solid form. However, this fact is not completely substantiated by Simpson (73).

He illustrates the use of gas oil and other aliphatic hydrocarbons in a continuous co-current contact process. In this process predried, finely divided ore is mixed, in a paddle type extractor, for about fifteen minutes with the required amount of solvent at 265°F, in order that complete sulphur dissolution and a fully saturated solvent is assured. Then the solids are filtered off and the hot solvent cooled. The sulphur crystals formed are subsequently collected by filtration.

An earlier and more detailed patent (18) and review article (17) by Bradley present a very similar process to the above. The main difference being the solvent recommended is an aromatic hydrocarbon based mixture and is counter-currently contacted in a helical screw conveyor with the feed material. Because solvent recovery is considered to be an important factor in the economic operation of this equipment an elaborate vacuum system has been described. It is intended that the residual solvent adhering to the tailings and sulphur product are removed essentially by vacuum filtration. Other parts of the process where solvent vapors are likely to be formed are similarly connected to a vacuum condenser prior to being returned to the solvent circulating streams.

An equally important aspect of economical operation, which appears to have been overlooked, is that of heat recovery. An obvious place, where savings could result, would be to partially cool the rich solvent by preheating the cold lean solvent before finally cooling with water to crystallise the sulphur. In this case water has been used indirectly to completely cool the solvent. This

has been noted as being a troublesome procedure since sulphur crystals have a tendency to grow on vessel walls rather than in the bulk liquid phase. Direct water injection as practised by McDonald (55) could alleviate this problem. Another poor feature of this technique is, in Dunning's (32) opinion, the screw flight contactor cannot provide sufficient agitation for satisfactory mass transfer of the sulphur to occur in the vessel residence times specified. Incidentally, Dunning advocates the use of an apparatus remarkably similar to Bradley's! Thus it can be said of the above approach that while the concept is functional the processing hardware leaves much to be desired. As outlined it opposes the Alberta unit's design philosophy due to its mechanical complexity and has certain inherent extraction inefficiencies.

Recently a new solvent extraction process developed by the Dubow Chemical Company (66) has been announced. The sulphur is leached with a hydrocarbon solvent e.g. kerosene, the wastes separated and the pregnant solvent cooled. Any entrapped solvent is recovered by a "special technique" from the sulphur product and is instrumental in reducing solvent losses to a minimum. Details of this route, which is claimed to be competitive with other methods, are rather sketchy at the present time and it has only been mentioned for completeness.

Other solvents that have been suggested include organic polysulphides such as dithiodiglycol, a bis- (alkanol) disulphide (21) and chlorinated hydrocarbons like perchlorethylene (55), and o-dichlorobenzene (18). Since these solvents tend to be expensive their use is not really practical from an economic standpoint due to

high costs arising from making good losses occurring in the tailings and product streams. Other difficulties, particularly with perchlorethylene, include the formation of azeotropic mixtures with the water content of the ore which can be difficult to separate. This constitutes an additional cause of solvent loss. An increase in viscosity as the solvent becomes more saturated with sulphur has also been found to be problematical in unit operations (21).

Mention of chlorinated hydrocarbons leads onto a review of a recently reported process (9) thought to be offered by Parsons (8). Finely divided ore is mixed with the solvent in an agitator and the gangue separated by a water wash. The sulphur is then precipitated by direct cold water contact. Product purity is claimed to be 99.5% or better and the recovery in excess of 90%. Solvent losses are minimised by steaming the tailings and product, before disposal, and condensing the vapors before recycling. Once again processing details are sparse so that a meaningful assessment cannot easily be made. An alternative to steaming for solvent recovery would have to be devised for a plant proposed for the Fort Vermilion area. Use of a hot inert gas has distinct possibilities.

Finally, carbon disulphide, because of its great dissolving power for sulphur, has been tried as a solvent but without much success mainly on account of difficulties arising from its disagreeable odour and extreme volatility. As a result of this readiness to vaporise, the processing technique employed is somewhat different to that applied to the other solvents so far considered.

Hutchins and Zwayer (43) describe in detail a method whereby crushed ore is contacted with heated carbon disulphide and the sulphur dissolved in an extraction column. The rich solvent is then evaporated in a still with steam at about 300°F and 53 p.s.i.g. and the molten sulphur collected as a bottoms product. The overhead vapours are condensed and the solvent returned, after separating by gravity any water present, to the extraction stage heater. Because of the solvent's unpleasant smell, measures are taken to prevent any vapour escapes and include an activated carbon adsorber connected to several parts of the plant where vapour build-up is likely to occur. The disulphide is removed by the charcoal and is periodically recovered by steaming. Occluded solvent in the gangue is similarly recovered by steaming or hot water treatment.

A process resembling the above has been suggested by Egbert (34) and Kemp (47) indicates his previously discussed route is suitable for carbon disulphide usage. However, this method, in addition to the operational problems outlined before, suffers, as do all the techniques advocating carbon disulphide, from the fact that the disulphide is prone to electric shock and explosion since its ignition point is very low. Another drawback is the high toxicity represents a danger to operating personnel in cases of leaks. Still another disadvantage is that the sulphur product no matter how treated retains the nasty odour of the solvent making it more difficult to market. These points coupled with the extensive use of steam, although the need for such high pressures cannot be explained, make the adoption of a carbon

disulphide processing route unlikely in this study unless a novel handling method can be developed.

A problem peculiar to solvent extraction approaches is that chemical reactions are known to take place between many of the solvents employed and sulphur. Therefore average extraction times and extraction temperatures have to be such that this occurrence is minimised. None of the reviewed material discussed this point in detail except one (9) where special additives are mixed with the solvent to inhibit the reactions. In any process development work utilising the solvent extraction method, this aspect will have to be closely examined. If unchecked expensive solvent losses and reduced sulphur recoveries could occur.

From this survey on solvent extraction methods it can be said that recovery by this means offers a convenient way of producing quality brimstone with a high degree of recovery. As some of the solvents i.e. the hydrocarbons are readily, and therefore cheaply, available in the deposit area, the route is possibly more suited for processing the Alberta ore than the other reported methods.

Discussion

To conclude the literature review it is considered that some general comments applicable to the processes studied and the raw material itself are warranted so that a reasonable basis for further investigations can be formulated.

First, it is interesting to note that all the processes reviewed include a crushing stage. Whilst this is necessary for ores of volcanic

origin it is believed that for the ore in question, because of its friable nature, this operation can be eliminated. As a result considerable savings could be achieved not only in the initial capital expenditure but in production costs as well.

The moisture content of the ore is crucial in determining the process heat requirements and some form of drying prior to the recovery operation is advisable. Some authors (17)(40) have indicated that this is a relatively easy operation but Dale (30) maintains that there is no suitable equipment currently available for this duty. Thus in this study this point will have to be resolved.

The possibility of finding a market for the gangue solids also warrants attention if as Kemp (47) points out any gypsum present can be used to make plaster or cement fairly easily.

Of the processes examined some improvement in heat utilisation could result in reducing the operating costs to a lower level. As previously indicated this aspect of the manufacturing operation seems to have been neglected particularly in the thermal and solvent extraction methods.

Another major improvement would be to reduce the amount of mechanical handling of the materials which forms such a large part of the reported techniques. These handling steps are considered to be both troublesome and costly to operate.

From the above survey it can be said that for the purposes of this study solvent extraction most closely approaches the design philosophy albeit with some modifications to reduce the equipment com-

plexity and operating difficulties. It is claimed (51) that the production costs will be somewhere between those of the Frasch process and the gypsum based process which suggests the final developed method will be comparable economically to other routes currently practised.

CHAPTER III

SOLVENT SELECTION

In order to develop a production method for brimstone within the design confines outlined earlier and applying the general conclusions taken from the literature review, it is necessary to make a preliminary selection of suitable sulphur solvents before undertaking a detailed experimental study. Selection at this point will be carried out on the following basis:

- a) solubility of sulphur in the solvent
- b) chemical properties of the solvent
- c) cost
- d) handling requirements, and
- e) availability.

Ideally, the solvent will be readily available, have a low cost, have few handling problems and be relatively inert chemically.

Solubility of sulphur in many materials is fully covered in two references (52)(75) and from these the initial choice of solvent can be made. Based on the maximum differential thermal solubility of sulphur, compounds such as carbon disulphide, carbon tetrachloride, p-dichlorobenzene, benzene, toluene, quinoline(39) and cyclohexane (20) can easily be selected as possible solvents. Also materials like olive oil, kerosene and gas oil deserve further study.

On examining their chemical properties some of these substances can be deleted from this selection. Quinoline, for instance, decom-

poses in the presence of water and is unsuitable in view of the fact that the ore is known to contain a certain amount of moisture. Similarly p- dichlorobenzene can be eliminated for under ambient conditions it is a solid. However the majority of these solvents can be discarded on account of their initial high cost. This cost is significantly influenced by the remote location of the ore body. Hence the processing operation would, if such solvents were employed, be uneconomic should even the smallest losses be allowed to occur.

As the deposit is located near plentiful, low cost supplies of petroleum products and carbon disulphide, the choice of solvent must inevitably fall on these materials. The literature survey showed that marketable sulphur could be obtained from an ore using any of these materials. As a result of the comments of Sax (70) on the toxicity of carbon disulphide and preliminary experimental tests, kerosene was selected as the solvent to be used in any developed extraction process. A higher boiling hydrocarbon such as diesel or gas oil could have been used instead of kerosene but was decided against since they more readily undergo chemical reaction with the sulphur. In addition they do not dissolve appreciably more sulphur per unit weight than kerosene for a given temperature.

CHAPTER IV

PROCESS DEVELOPMENT OUTLINE

At this point it is advantageous to broadly discuss the process development work undertaken to provide a background for the subsequent chapters in this study.

From the preceding sections the basic solvent extraction route for processing the native sulphur ore has been established. Mixing the ore with hot kerosene to dissolve the brimstone constitutes the first step. This is followed by separation of the gangue from the rich solvent. Finally the sulphur is crystallised and separated from the kerosene. Figure 1 schematically illustrates the process.

In developing this route experimental work was carried out to demonstrate the capability of the processing steps in handling the Alberta ore. For example, the mixing and dissolution characteristics of the raw material were investigated to find the most suitable treating method. Similarly kerosene retention by the solid wastes and its reduction to a tolerable level was examined. Physical data not found in the literature was also obtained. In this regard determination of the sulphur-kerosene solubility curve should be mentioned.

From the results of this practical work, the detailed processing route shown in Figure 13 was evolved. Based on this flow sheet, a computer plant design program was written to size and cost estimate the solvent extraction unit. The plant operating conditions were then established by optimising the design to yield the smallest manufacturing costs.

Whilst it is realised that the experimental aspects and processing techniques of this method are closely interrelated, it is proposed to discuss them separately in the coming sections

CHAPTER V

EXPERIMENTAL WORK

In order to determine the most efficient processing technique and to provide design data needed for sizing the handling equipment, an experimental programme was undertaken. This chapter describes this work. System characteristics arising from the results and their bearing on the choice of handling method are also covered.

Solubility data

At present there is no sulphur solubility data for kerosene at different temperatures in the literature. To measure the sulphur content of a saturated kerosene solution several methods are available. They include:

- a) crystallisation,
- b) x-ray analysis,
- c) flame photometry,
- d) a light transmission or refractive index method, and
- e) gravimetric technique.

The first four methods require test solutions for calibration purposes containing known quantities of the constituents. In addition they present practical difficulties such as maintaining the sample temperature at the sulphur crystallisation point so that a fully saturated solution is assured whilst taking the measurements. The gravimetric approach overcomes these problems although it is somewhat time consuming.

Essentially, a sulphur saturated solution of known weight and temperature is evaporated to dryness, cooled and reweighed. The solubility is then calculated from the weight changes given the original sample container empty weight.

However in determining solubilities with this approach, there are two sources of error that have to be accounted for. The first of these is due to the time involved in weighing the sample. Because the sample is normally at a temperature in the range of 130°F to 195°F, some of the kerosene will vaporise in this period. This results in a measured weight that is lower than the true value and hence will yield a higher calculated solubility value. To gain some idea of the magnitude of this error, tests on the weight change of a solvent sample of known temperature, standing in air, with respect to time were carried out. Sampling time was considered to be zero and weighings were noted relative to an elapsed time from the instant of sampling. From this data, a fictitious weight for the point of sampling was calculated using a difference table technique described by Conte (26). To calculate the correction factor to apply to a sample weight actually measured, the first weight noted in any test was normalised with the fictitious zero time weight applicable to that test. Correction factors relative to the time taken to obtain the first weight of the sample, t_s , are shown in table 1. Also shown are correction factors relative to the average weighing time, t_{AVG} , i.e. the mean of all the times taken to obtain the first sample weight in each of the tests carried out.

The errors indicated were calculated assuming there is an upper

and lower limit to the accuracy to which the weight and time measurements can be made. In this case weight readings were considered reliable to within 0.0005 gm. and time measurements to within 1 second. Once a correction factor had been calculated, without allowing for measurement limitations, two other factors were then found denoting the maximum and minimum deviations from this value. The percentage error shown after each of the factors in table 1 represents the maximum difference between the correction factors expressed as a percentage of the original factor. Thus it can be seen that no significant error exists in the correction factor values allowing for measurement limitations.

The correction factors pertaining to t_{AVG} over the temperature range examined were incorporated into the solubility calculation, which will be covered in more detail later. The reason for using these values is that they are considered more representative of experimental conditions than the factors relevant to sampling times measured for each test. From table 1, it can be seen that as the temperature increases, the weight correction required also increases. This is explained by the greater evaporation rate experienced at higher temperatures.

The second source of error occurs with the drying of the samples. To evaporate the kerosene a fairly high temperature, about 300°F, should be used. Sulphur, being a liquid at these conditions, tends to vaporise too. This leads to a false dried weight and hence a lower calculated solubility value. In order to minimise this possibility a drying oven temperature of about 200°F was employed to ensure molten sulphur was not formed. Length of drying similarly affects the result because even

solid sulphur will sublime under suitable conditions. A check was undertaken to estimate this phenomena using an analysis, again, based on the difference table approach. The drying time correction factors thus determined are shown in table 2. They relate the measured heating time for a sample to a specified time interval, usually 45 minutes. These factors were also included in the solubility calculation.

For the solubility measurements the sulphur and kerosene were supplied by Imperial Oil Limited. The kerosene had a boiling point of 360°F, a flash point of about 140°F and a specific gravity of 0.79.

Solubility determinations were made at several temperatures using solutions that had been stirred for about an hour to ensure complete saturation. Saturation was achieved in the apparatus shown in figure 2 and sample weighings were made on an electric Mettler Balance, type H6.

The calculated solubility values, shown in tables 3 to 9, were based on a solution weight allowing for weighing time errors and a dried weight corrected for heating time errors. Again an error estimate, as outlined previously, was applied to the calculations. The accuracy of the results is observed to improve as the solution temperature increases. This is because the solution sulphur weights, being greater at higher temperatures, are less influenced by the accuracy limits imposed by the error estimates.

A solubility curve plotted from these results is given in figure 3. The data points indicated are based on a fictitious drying time of 45 minutes.

All the results obtained in this part of the practical work were calculated by computer. Appendix I shows the programs, written in Fortran IV, that were used for these determinations.

Thermal gravimetric analyses

Before proceeding with a description of the experiments performed in the development of a suitable beneficiation route, the work undertaken to establish sulphur and moisture contents of the ore samples available will next be covered.

Since the quantity of ore samples was limited, an analysis technique employing small amounts of material was needed as opposed to the usual macroscopic carbon disulphide method (71)(75). A thermal gravimetric approach satisfies this criterion. The method consists of placing the sample in a weighing balance scale pan, heating the material at a controlled rate and observing the weight change with increasing temperature. In the equipment used, a Du Pont type 950 Thermal Gravimetric Analyser, this weight change was followed electronically and displayed by a pen recorder output, see figure 4. Any volatile components present in the test materials, in this case water and sulphur, will evaporate off over distinct temperature ranges. Thus their portion of the total sample weight can be identified as a series of weight changes separated by plateaus. By noting these changes the composition of the material can be calculated. To prevent possible reactions between atmospheric oxygen and the sulphur and organic material of the samples, the apparatus was continually purged during the heating period with nitrogen.

The curve shown in figure 4 was produced by heating an Alberta ore sample. The first plateau represents the initial weight of the material in the balance pan. The weight change occurring in the temperature range 80°C to 130°C constitutes the evaporation of the moisture content. A possible explanation for such a large range, rather than a narrow band about 100°C , lies in heat transfer and diffusion effects. In the apparatus, the temperature is measured by placing a thermocouple very close to, but not in contact with, the sample. Heating is accomplished by using an electric furnace that completely surrounds the balance arm. Thus it is possible the measured temperature represents that of the ore surface rather than its interior at any given instant. This implies the existence of a temperature gradient within the sample. Because of this gradient bonded water present in the centre of the solid will be liberated at an apparently higher temperature than is the case. The weight change resulting from the evolution of this moisture will only be seen once it has diffused out into the purge gas stream. One way of minimising this effect would be to reduce the heating rate. In these experiments a rate of 15°C per minute was used. However for the purposes of these tests only the weight changes are important and are not affected by the heating rate.

Similarly the second weight change results from the sublimation of the sulphur content of the ore. Again, due to heating and diffusion effects, sublimation occurs over a large temperature range. As the temperatures involved are below the sulphur boiling point, these experiments demonstrate the ease with which brimstone is liberated by sublimation.

This interpretation of the curves obtained for the ore samples was confirmed by tests on water and sulphur alone. Observed weight changes took place in the same temperature ranges to the above.

In the case of sample #3, which was found not to contain any sulphur, a weight loss nevertheless occurred over the sulphur sublimation range. This is thought to represent thermal decomposition of the organic material in the ore. This loss is recorded as a linear weight decrease extending to temperatures in excess of the sulphur sublimation limit. A similar test on garden soil, known not to contain sulphur, exhibited the same behavior. An allowance for this material evolved over the sublimation range can be estimated by extrapolating the recorder trace, produced at high temperatures, back to the onset of brimstone evaporation. By applying this correction to the sulphur bearing samples the true weight contained in the ore can be found.

The analysis results of the material examined are summarised in tables 10 and 11. The sulphur content was found to vary from 8.0% by weight, on a water free basis, to 53.5%. The moisture content was approximately 9.0%. This value is considered to be lower than that naturally occurring since the ore had been stored for sometime before testing and had had a chance to dry. As the moisture level is not typical the majority of the analyses estimated the brimstone content only. For this reason the results in table 11 are expressed on a water free basis. It can be seen that the sulphur content of samples originating from the same location varies considerably. Therefore, unless many analysis results are available, the average sulphur content

of the ore cannot reliably be estimated by the thermal gravimetric method. This is due to the very small size of sample required for the analysis.

Sulphur product purity tests were performed on this equipment. In the literature survey it was indicated that the sulphur could be separated from the solvent by filtration. This procedure has been suggested for this extraction route. In order to simulate actual filtration conditions, the brimstone analysed was crystallised from a hot kerosene solution using a water quench and the sulphur allowed to collect in the water phase. This mixture of water and sulphur with occluded kerosene was then filtered followed by water washing and air drying of the filter cake. Brimstone samples were taken, for analysis, before and after this washing operation.

Since sulphur is not preferentially wetted by water, any material evolved in the analysis before the onset of sulphur sublimation must be kerosene. This is confirmed on two counts. The indicated temperature range over which the first weight change took place corresponded to that produced by pure kerosene. By analysing filtered sulphur that had been water wetted for several hours demonstrated that water is not retained by the brimstone crystals.

Samples were taken before and after the washing operation so that the effectiveness of the wash could be estimated. This information being required to complete material balance calculations around the filter.

An alternative method outlined by Tuller (75) of igniting weighed amounts of sulphur and reweighing the solid residues was not

used. This was because any solvent contained in the brimstone would also be burned and thus not report as an impurity.

The results of these tests are summarised in table 12. The sulphur purity indicated is unacceptable to most consumers. However, examination of the analysis trace shows that the impurities are driven off below a temperature of 150°C. The remaining trace does not show the presence of any other contaminant. As this aspect of the processing route is not critical, it is suggested that final drying with hot air or inert gas would be sufficient to remove the last of the solvent.

Some manufacturers (1)(71) claim that visual inspection of the sulphur crystals is satisfactory in determining the product purity. Very small amounts of impurity are capable of changing the bright yellow colour of brimstone considerably. No visible colour difference could be established between sulphur crystallised from kerosene and that known to be 99.5% pure. This fact supports the above observation that the brimstone is only contaminated by volatile materials and not small quantities of solid compounds such as carbon.

The wash water ratio i.e. the amount of water used to wash a unit mass of sulphur product, would appear to be important in reducing the kerosene content of the cake. A ratio of 7.65 gave the lowest impurity level in the sulphur crystals collected. However a ratio of 1.0 will be used in the design calculations since it is considered the experimentally determined ratio is wasteful in water usage. By careful spray design a wash ratio of 1.00 is assumed to be adequate for satisfactory product washing.

The above crystal preparation and analysis work is of a preliminary nature and should for actual design work be augmented by further data. A reduction in the solvent content of the product is believed to be relatively easy to attain. Possibly a more efficient filtration operation may be all that is required. Further investigations are necessary before detailed design work is undertaken.

The thermal gravimetric analysis technique was also applied to estimate the solvent retention by the gangue. Once the sulphur had been extracted from the ore by the solvent it was proposed to wash the solvent-ore slurry with hot water. This three phase mixture would then be allowed to separate into a water-gangue slurry and a clarified solvent layer.

In analysing the ore wastes it was found that the water and kerosene tended to evaporate at the same time. Hence there was no way of determining the relative amounts of these materials present in the sample. Thus an alternative way of finding the kerosene content of the solid wastes was needed. This will be discussed in a later part of this chapter.

From this aspect of the analysis work it can be said that provided the materials present in a sample have evaporation ranges that are widely separated then the method is satisfactory. For the case of water and kerosene where evaporation takes place partly over the same temperature range, this technique is not recommended.

Dissolution rate determinations

As previously indicated, the ore-solvent contacting methods described in the patent literature are suspected of being inefficient. Mixing tests with an agitator were tried in the hope that they would prove more successful.

The apparatus used is diagrammatically illustrated in figure 2. It consists of a 2000 ml. jacketed reaction vessel, manufactured by the Scientific Glass Apparatus Co. Inc., an air driven stirrer and a steam-water heater for providing hot water to heat the vessel contents. Since the ore samples were in short supply, a synthetic ore of crushed sulphur and garden soil intimately mixed together was employed initially. The sulphur content was 20% by weight and represented the approximate sulphur content of the ore. The particle size of this material varied from a $\frac{1}{4}$ inch size down to dust fines.

After a known quantity of kerosene had been heated to the desired temperature, the artificial ore was added so that a slurry of about 15% by weight solids was formed. Stirring was started and liquid samples withdrawn at cumulative stirring time intervals that formed a geometric progression i.e. after 1, 2, 4, 8, and 16 minutes of agitation. In this way the initial rapid dissolution could be followed. Once the required stirring time interval had elapsed, agitation was stopped and the solids allowed to settle. This was to minimise fines contamination of the liquid samples taken. After two minutes settling, the first sample was withdrawn followed two minutes later by a second sample.

Agitation was then restarted. During the settling period it

was assumed that none of the sulphur would dissolve in the solvent. The samples were analysed for brimstone content by the gravimetric technique mentioned earlier. Two samples were taken to provide a consistency check on each determination.

The initial runs made with the synthetic ore showed that the kerosene would dissolve the sulphur in a reasonably short period of time. Consequently tests were made on the Alberta ore, samples #1 and #5 in table 11. The ore used originated in Lambert Creek, about fifty miles south-east of Fort Vermilion. The results of all the experiments are summarised in tables 13 to 21 and dissolution curves presented in figures 5 to 8. Table 22 gives details of the slurry concentrations and ore types used in these tests.

From these results it can be seen that both the synthetic and real ores exhibit similar dissolution characteristics and required up to twenty minutes stirring in order to sulphur saturate the solvent. Saturation is shown by the horizontal straight line portions of each curve. Agreement, within experimental limits, can be observed between these saturation values and those of the solubility curve for the same solution temperature. It will be noted that in some cases the kerosene was saturated in less than twenty minutes. However, use of this stirring period is recommended for design calculations since it will provide a margin for error.

A decrease in the amount of sulphur dissolved in the kerosene with prolonged stirring is shown by most of the curves in figures 5 to 8. During stirring hot solution is continually splashed onto the un-

heated parts of the apparatus e.g. the steel cover, see figure 2. Here it cools causing the sulphur to crystallise out of solution and adhere to the equipment. To maintain a saturated solution more sulphur will dissolve from the ore. This takes place until it has all been dissolved. The deposition process, however, still continues resulting in the decrease in the solvent sulphur content.

This reasoning is substantiated by the results of the tests carried out on the artificial ore at 171°F and 185°F, see figures 6 and 5 respectively. In these tests 225 gms. of a 20% wt. sulphur ore were slurried with 1425 gms. of kerosene. This yielded a 13.7% wt. solids slurry. To dissolve all of this sulphur and form a saturated kerosene solution a temperature of 173°F or greater is required. At these conditions the sulphur content of the solvent will be 0.032 gms. per gm. of solution. However in the experiments the sulphur content did not rise above 0.029 gms. per gm. solution in spite of the temperature conditions favouring more dissolution. Thus it can be concluded that deposition prevented saturation from occurring.

From the experiments performed using temperatures below 173°F it can be seen that the solvent is saturated within a twenty minute stirring period regardless of the kerosene temperature. Thus this stirring method can be adopted for full size plant operation provided the mixing vessel walls are not allowed to cool below the solvent saturation temperature. Dissolution temperatures should, of course, be sufficient to ensure all of the sulphur contained in the feed material will be dissolved.

On adding the ore to the kerosene, the temperature was observed to drop and then as stirring progressed slowly rise to its original value. As the ore was at room temperature and the solvent at about 160°F, some decrease in the liquid temperature was to be expected on mixing the slurry. The mixing illustrates that no detrimental effects are caused by adding the ore in this way and can be advocated for a commercial plant.

Throughout the dissolution rate experiments, the solution was carefully examined for discolorations and the sulphur resulting from the evaporation of the liquid samples for tarry residues. Such occurrences are considered indicative of a chemical reaction taking place between the sulphur and the kerosene solvent. No such observations were made even at the highest temperatures employed. It is concluded that the conditions prevailing in the experimental runs do not noticeably foster reactions between these materials.

With the Alberta ore it was found, when stirred, to break down into very fine particles which on settling become floc like in appearance. This material was fed to the mixing vessel without prior crushing and its particulate size ranged from a maximum of $\frac{1}{2}$ inch down to dust fines. The ease in breaking up on agitating suggests that in any commercial unit the crushing step, referred to in the literature, will not be needed.

From these results it can be said that mixing the ore in the manner described will provide satisfactory dissolution of the sulphur values of an ore body and its adoption on an industrial scale can be envisaged.

Mixing power experiments

The part describing the stirring of the ore indicates that the method employed is satisfactory in achieving total dissolution of the sulphur values. Therefore, it is necessary to determine the mixing power requirements of the ore slurry to enable vessel scale-up calculations to be made with a reasonable degree of reliability. Power requirements for this slurry type could not be located specifically in the literature. Consequently tests were undertaken on several slurries of differing solids content to obtain the mixing power data.

The experimental procedure adopted is described in the Fluid Agitation Handbook (6) and by Rushton and co-workers (67)(68)(69). The apparatus employed, shown schematically in figure 2, was a Chemineer Experimental Bench Agitator, model ELB, consisting of a "standard tank" (one with a flat rather than dished bottom) with detachable baffles of varying widths, a variable speed electric motor and drive capable of providing speeds between 0 and 1175 r.p.m., and a set of different impeller types. For our purposes the flat and pitched bladed turbines were used, being recommended (6) as most suitable for suspension duties. Also a spring dynamometer was fitted to the impeller shaft so that available shaft torque measurements could be taken. Shaft rotational speeds were found using a model 1531-A stroboscopic tachometer manufactured by the General Radio Company of Concord, Massachusetts. Experimentally, slurries of known solids content were stirred in several baffled tanks of different diameter using various turbine sizes. Rotational speeds sufficient to ensure that the solids were completely

suspended were employed. The ore used was an artificial one assaying about 25% by weight brimstone. Also varied in these tests was the slurry temperature.

From the shaft torque and r.p.m. measurements, the Reynolds and Power Numbers and the motor horse power were calculated by applying the following formulae:

$$\text{Horse Power H.P.} = \frac{(\text{torque lbs}_f.) \times (\text{shaft speed r.p.m.}) \times (\text{moment arm in.})}{63025} \dots (1)$$

$$\text{Reynolds Number } N_{Re} = \frac{\rho N D^2}{\mu} \dots (2)$$

where ρ : fluid density lbs_m/ft^3

N : shaft speed r.p.s.

D : impeller diameter ft.

μ : viscosity $\text{lb}_m/\text{ft}.\text{sec.}$, and

$$\text{Power Number } N_p = \frac{Pg}{\rho N^3 D^5} \dots (3)$$

where P : power $\text{ft}.\text{lb}_f/\text{sec.}$

g : gravitational constant $32.12 \text{ lb}_m \text{ ft}/\text{lb}_f \text{ sec}^2$

A computer program employing the above formulae was written to calculate the results of these experiments. The program listing is contained in Appendix II and the results shown in tables 23 to 46.

From this data it can be seen that a six bladed turbine having a blade pitch of 45° requires less power for mixing at a given shaft speed than an impeller having flat blades. Table 47 summarises data illustrating this point. It was also observed that the pitched blade

turbine kept the solid material in suspension far more readily than the straight blade type. This was true at all slurry concentrations tested up to 17.9% wt solids. Above this level material tended to remain on the tank bottom and slowly circulate. Thus sulphur extraction under these conditions would become rather inefficient. Therefore a pitched blade impeller is recommended for mixing duties in any commercial installation. The limiting solids concentration, outlined above, is also advised as an upper limit for use in plant design calculations.

To explain the analysis of the data a brief description of the curve indicating the relationship between the Power and Reynolds Numbers is necessary. Usually mixing data is taken for Reynolds Numbers ranging from 0 to about 10^7 . For a six bladed pitched turbine (12) the curve characteristically decreases from a Power Number of 10.1 to one of 2.0 over the Reynolds Number change 5 to 100. In the transition range the Power Number levels off to a value of 1.3. Under all turbulent conditions i.e. at Reynolds Numbers above 10^4 , the Power Number remains constant at 1.3.

For the ore system complete solids suspension is unattainable at Reynolds Numbers below about 5×10^5 . Under these conditions the solid material will stay on the vessel bottom and slowly circulate. As these conditions are not conducive to good mixing they were not examined. The data presented in this study apply to high Reynolds Numbers.

By averaging the Power Numbers for the pitched turbine runs, a Power Number of 1.30 is obtained for the Reynolds Number range examined. Figure 9 shows representative data for these tests of the Reynolds

Number - Power Number relationship. The solid line indicates the observations of Bates et al (12) that apply for a similar turbine and tank configuration. It can be seen that the curve of Bates (also formed by averaging the results) agrees, within experimental limits, with the observations made on the artificial ore and kerosene slurries.

The discrepancies in the calculated Power Number value can in part be attributed to difficulties experienced in taking the torque measurements. Under test conditions the spring gauge reading would oscillate rapidly. Therefore a torque measurement was estimated from the maximum reading obtained from about two minutes observation. Allowing for the oscillation, about 0.02 lbs_f , in the calculations, an estimated error for the Power Number of about 15% was obtained. This figure compares with that suggested by other workers for this Reynolds Number range. Again the errors were determined by the method outlined in the solubility curve section.

Normally results of mixing experiments are plotted on logarithmic coordinates and cover Reynolds Numbers varying from 0 to about 10^7 . The data for the artificial ore cover only part of this range i.e. $5 \times 10^5 < N_{Re} < 10^7$. The reasons for examining such a limited range have been given before. Whilst a linear plot would have been satisfactory in presenting these results, a logarithmic plot was used simply to avoid confusion.

Temperature increases in the slurry cause a reduction in the motor horse power requirement to ensure a completely suspended solid slurry is formed. Tables 41 to 45 illustrate this point. To provide

a design safety margin in plant scale-up considerations, the motor power calculations should be determined for ambient conditions. '

To sum up it can be said that satisfactory mixing data have been obtained for a slurry of artificial ore and kerosene. Confirmatory tests are required on the Alberta ore before agitator specification can be considered reliable. However for the purposes of this study, in view of the reasonable agreement between this data and that of other workers, differences, if any, are not believed to be significant.

Gangue solids washing

Once the brimstone has been dissolved from the ore, separation of the ore wastes from the saturated kerosene is necessary so that only clarified solvent enters the next stage of the extraction process. Simple gravity settling will achieve this objective but a large proportion of the pregnant solvent will remain associated with the gangue. This is undesirable as this solvent and dissolved sulphur then represent losses to the system.

Washing with water, as practised with other solvents (34), was tried in an attempt to free as much of the solvent as possible from the tailings. This technique also produces a water-gangue slurry which is more easily disposable. In accomplishing this, kerosene and consequently sulphur losses are reduced and solvent make-up requirements minimised. A potential pollution hazard resulting from contaminated tailings is also avoided. A water temperature equal to that of the hot solvent is needed to prevent the premature formation of sulphur crystals due to cooling.

Experiments were conducted in a calibrated vessel (see figure 2) containing a known quantity of kerosene-ore slurry which had been stirred until the ore was completely wetted by the solvent. A synthetic ore was again used for these tests. A known amount of water was added and the respective volumes of the liquid phases measured using a cathetometer. The mixture was then stirred violently for about ten seconds and the phases allowed to separate once more before measuring the phase volumes. This procedure was repeated several times until no significant volume change occurred. The experiment was repeated using different volumes of water keeping the temperature and solvent slurry concentration the same.

From these measurements the solvent retention capacity of the ore wastes was found by subtraction. Table 48 gives the experimental details of the solvent ore slurry prior to washing and table 49 the kerosene retention capacity. The results show the solvent losses for the measured case and for the worst case allowing for measurement errors. For the worst case it can be seen that on adding the hot water to the slurry about 96% by volume of the solvent is separated from the solid materials. The volume of water used seems to have little effect on the amount separating from the solids.

Subsequent agitation of the three phase mixtures to reduce the gangue solvent content proved to be inconclusive. This was due to scum build up making it difficult to measure accurately the phase volumes. For the lowest water to solvent volume ratio examined, stirring reduced the kerosene content of the tailings without any scum formation. For all the other cases scum formation occurred with very little agitation.

With continued stirring it became progressively worse until a stable emulsion was formed. Such emulsions are undesirable as they constitute an additional source of solvent loss. Thus it can be said that for washing operations the smallest wash ratio employed and the least stirring time give the best degree of solvent removal from the solid wastes.

From these stirring tests it was found that a minimum quantity of water per unit volume of solvent exists above which a stable emulsion of kerosene, water and solids will form. This emulsion forms very quickly on agitating the mixture regardless of stirring speed. It will not collapse on standing overnight, by the action of surfactants or through mild agitation. Although an emulsion will form with water volumes below this critical value, it will break down fairly easily under mild stirring action. The development of the stable emulsion with the increasing water to solvent ratio from a scum is qualitatively discussed in table 50.

From this series of tests it is suggested that washing the gangue with hot water offers a method of separating it from the rich solvent. Extreme care is required in the operation to ensure that the water to kerosene ratio is kept well below the critical value for stable emulsion formation.

Even when using the smallest water washing ratio, the amount of kerosene retained on the ore is excessive. Such levels, if permitted in plant operation, represent an intolerable operating expense. Therefore air agitation of the water-gangue slurry was tried in an effort to reduce this loss to a more acceptable quantity.

Simple experiments of blowing air through freshly washed tailings were undertaken. These tests indicated that further kerosene 'could be released from the solid materials without difficulty. However a certain amount of scum was formed. This is understandable when it is realised that the water to kerosene ratio is well above the critical value referred to previously.

One potential problem with using air is that an explosive mixture is formed with the solvent vapours under normal operating conditions. It should be recalled that kerosene has a flash point of about 140°F. Normal plant operating temperatures are expected to be somewhat higher than this figure. Use of an inert gas such as nitrogen or carbon dioxide can overcome this difficulty.

To sum up, hot water washing of the ore-solvent slurry offers a method of separating the majority of the kerosene from the ore wastes. Unacceptable retention levels by the gangue and the ease with which an emulsion is formed, constitute the disadvantages of this approach. Agitation is not necessarily beneficial in liberating the final traces of solvent occluded on the gangue. Gas agitation of partially washed tailings holds potential for lowering solvent losses.

More work dealing with gas agitation of the tailings is needed to resolve this point. The Alberta ore should be employed in this work rather than an artificial material.

Sulphur product crystallising and washing

In the literature review it was indicated that direct contact of the cooling media with the sulphur saturated solvents was the best

technique available to produce the brimstone crystals. This is because vessel blockages due to crystal growth on the walls are avoided. For this reason it was decided to adopt this approach in the process development work undertaken on the Alberta ore.

Similar experiments to the above were carried out on hot kerosene solutions but using cold water in varying proportions. Irrespective of the water to kerosene volume ratio employed no emulsion could be formed between the water, kerosene and precipitated brimstone.

During the course of these tests it was observed that the crystallised sulphur, on account of it being preferentially wetted by the solvent, would collect at the kerosene-water interface when the mixture was allowed to settle. Once a sufficient amount of sulphur had collected at the interface, however, most of it would fall through into the water phase in an oil like globular form. The sulphur is preferred in a water media for the vacuum filtering operation as an explosion risk is eliminated.

From an operational view point, the tendency of the sulphur particles to settle at the interphase boundary could be undesirable in certain instances. Interfacial injection of iso-propyl alcohol, to reduce the liquid surface tensions to enable the crystals to enter the lower liquid layer, has been found effective in overcoming this occurrence.

Solid phase settling

In the foregoing it has been intimated that the solid materials in the gangue-water slurry and the sulphur precipitate are to be con-

centrated by sedimentation. To determine the settling rates of these materials an experimental method described by Coulson and Richardson (28) was employed.

Basically a 1000ml. graduated cylinder, placed in a water bath, was filled with a slurry of known solids concentration and agitated with an air driven stirrer. The suspension was allowed to settle and the falling liquid suspension interfacial height noted with respect to time. A small quantity of liquid was then withdrawn, to produce a slurry of a higher solids content and the test repeated. The experiments were carried out on the above mentioned slurries at their respective operating temperatures.

The results obtained for the settling of the Alberta ore wastes are shown in table 51. The temperature employed in these tests was the maximum obtainable from the laboratory hot water supply. Although it is somewhat lower than that anticipated in actual operations, the difference is not believed to be significant enough to cause large changes in the observed settling rate.

During settling the gangue became floc-like in appearance. This is due to the agglomeration of fine particles. It has been reported (65) that the addition of chemicals, that readily ionise, to the suspension will increase the amount of floc formed and produce a faster solids settling rate. This is because ionisable materials, such as caustic soda or sodium chloride, provide the necessary ions in solution for the fine solid particles to associate with and thus agglomerate into larger ones.

To examine this effect 10 ml. of sodium hydroxide solution was added to the gangue suspension and the sedimentation tests repeated. As expected an increase in the solids settling rate occurred. The results in the second part of table 51 illustrate this point.

Figures 10 and 11 show the initial portion of the sedimentation curves obtained for the Alberta ore tailings. The initial acceleration period is followed by constant velocity settling over the range examined. Compaction of the deposited solids was not investigated as it is unlikely that the thickening vessels will be operated under these conditions.

For plant settling operations it may be beneficial to add some caustic soda, or similar, to the suspension to improve the sedimentation rate. A neutral or slightly alkali suspension pH may provide the most satisfactory conditions.

Table 52 shows the calculated sedimentation rates for each suspension. Also shown is the settling parameter. This is defined by the settler area formula i.e.

$$A = \frac{(U - V)}{(u_c)} \frac{W}{\rho} \quad \dots(4)$$

where A : area ft²

U : initial liquid concentration of suspension, lbs H₂O/lb solid

V : final liquid concentration of suspension, lbs H₂O/lb solid

u_c : suspension settling velocity, ft/hr

W : thickener feed rate, lbs_m/hr

ρ : slurry density, lbs_m/ft³

This parameter first increases in value to a maximum and then decreases as the suspension solids content rises. In plant settler design calculations the settling rate that corresponds to the maximum value will be used as it will yield the largest and consequently the most conservative settling area.

With the sulphur slurry no distinct liquid solid interface could be discerned, as was the case with gangue suspension. An estimate of the sedimentation rate was made, however, by observing the build up of the deposited sulphur layer at the cylinder base. For this material, no further compaction took place after the initial settling was complete thus representing a limit on the solids content of the thickened suspension. This will be the feed composition to the vacuum filter, proposed as the final stage in the processing operation.

The results of these experiments are summarised in table 53. The estimated sedimentation rate is compared to that calculated from Stokes Law. Since the accuracy of these tests was not good the minimum value will be used in design calculations so that a reasonable safety margin is assured.

Also observed, in this work on the sulphur suspension, and attributed to the violent nature of the stirring action needed to produce the slurry, was the formation of sulphur spheres about $\frac{3}{8}$ inch in size. These spheres, while easily crushed between the fingers, were strong enough to withstand agitation and therefore reservations about the effectiveness of the filtering operation are held. If the filter is fed by a screw pump, rather than by gravity, it is considered that the

pumping action will destroy any spheres that may form and any operating difficulty avoided.

Filtration experiments

In order to establish design parameters for the suggested filtration step, experiments were undertaken to determine the filter media and cake resistances. Such experiments are described in McCabe and Smith (54) and Purchas (64).

A sulphur slurry was formed by allowing freshly precipitated crystals to settle in water to their maximum consolidated state. This slurry was then filtered in a Buchner funnel fitted with a paper filter media and attached to a 500 ml. graduated cylinder. The cylinder was kept under a vacuum to provide a pressure drop across the filter. This arrangement was used as it most closely resembles a top feed rotary vacuum filter. This type is envisaged for the filtering operation because of sulphur's free settling characteristics.

From figure 12, showing the filtrate collection rate, it can be seen that the rate does not vary over the range tested. As shown in Appendix III this is because the sulphur filter cake does not offer any appreciable resistance to the filtering process. All the resistance occurs in the filter paper. This resistance was calculated from the experimental results.

This value will be used in the design calculations for the filter. However it should be pointed out that since no industrially used filter media could be obtained for testing purposes or their resistances found in the literature, this value employed is not strictly representative.

Discussion

The above outline of the experimental work undertaken demonstrates the feasibility of the various aspects of the solvent extraction process. The handling methods are within the stipulations of the design philosophy. This information will be used in the coming sections as the basis for a plant design. The plant will be designed specifically for treating the Alberta ore.

At this point it should be stated that most of the data obtained apply to the artificial ore. These results are not necessarily applicable to the native sulphur bearing ore. Further tests to verify the results are needed using the real ore. However the data available is considered to be suitable for initial design estimates.

The critical aspects of this processing route are the mixing characteristics of the ore and the solvent retention properties of the solid wastes. Further investigations to support the findings presented in this work are needed in this regard.

CHAPTER VI

PROCESS DESCRIPTION

The previous chapters in this work have served to indicate the more important handling features of the solvent extraction process. In this part all of the aspects covered thus far will be combined and discussed as the basis for a plant capable of processing the Alberta ore.

Basically the process as drawn in the block diagram, figure 1, consists of a sulphur extraction or mixing section, a tailings separation stage and a brimstone crystallisation section. The detailed processing steps involved are shown in the process flowsheet, figure 13. The following description is applicable to this diagram.

Mined ore, typically containing between 20% and 25% by weight brimstone, is fed to the unit on a conveyor belt, C-1, which passes through a dryer, not shown in the diagram, so that the moisture content of the ore can be reduced to 12% by weight or lower. This is necessary for in some of the mixing experiments where freshly collected material was used, the violent nature of the stirring action was unable to break down the soil particles when slurried in the solvent. This was because the water content of the material was substantially higher than the observed average 9% by weight. Some authors (41)(16) advise this figure also because heating requirements, to bring the fresh ore up to the processing temperatures, are less with smaller amounts of water present in the feed material. The dryer may be directly or indirectly heated using, for example, the flue gases discharged from the fired

solvent heater, E-1. If drying by direct contact of the ore with these gases is envisaged, then the gases should not contain any free oxygen otherwise some sulphur dioxide could be formed through ignition of the brimstone. This implies that the fired heater will have to be operated with an air supply that is below the stoichiometric requirement. This mode of furnace operation is undesirable as it is expensive. Another potential problem, that exists with the indirect method too, is to keep the solids temperature below the melting point of the sulphur. This will ensure particle agglomeration and blockages resulting from material sticking to the vessel walls will be avoided. An indirectly heated rotary dryer would seem to be the most suitable type of equipment to specify for this service.

The partially dried ore then enters the first of a series of mixers, A-1, by means of a star feeder or screw conveyor. These are claimed (41)(55) to prevent undue solvent vapour losses since any route open to the atmosphere is always filled with feed material. Here it is mixed with hot solvent, in this case kerosene, in order to dissolve the sulphur values. These agitators are a direct scale up of the bench sized apparatus used for the mixing power determinations. They provide a mean residence time equal to that experimentally determined as necessary to saturate the solvent. Geometric and dynamic similarity are maintained between the two vessel sizes as outlined in the scale up techniques presented by Chapman et al (22) and Uhl et al (76).

It will be noted (table 84) that three agitators in series are specified for the plant. This arrangement gives a measure of operational

protection in case one of the stirrers becomes unservicable and will, thus, prevent an unscheduled shut down. In addition, this set' up tends to ensure that the majority of the ore particles remain agitated long enough to have all the brimstone content removed. If one mixer was employed it can be argued (53) that some particles, because of the random nature of the liquid motions in the mixing process, would leave the vessel almost as soon as they entered it. Obviously any sulphur contained in these particles would not be dissolved and represents a loss to the system.

It can be seen from the heat and material balances that the solvent is mixed in such a proportion to maintain a slurry of about 15% by weight solids. The temperature of the solvent is above the minimum required for complete solvent saturation with the given brimstone loading. This aids the dissolution in that the driving force for mass transfer is prevented from tending to zero as the kerosene sulphur content increases.

The slurry is contacted, on leaving the agitators, with a carefully controlled quantity of slightly alkaline hot water to wash the gangue solids free of the pregnant solvent and pumped to the first settler, S-1. To provide the well mixed conditions needed for thorough washing orifice mixers can be installed in the sand pump, P-2, discharge line. This arrangement also ensures a short contact time thus minimising emulsion formation. As will be explained later, the hot water is initially at a slightly lower temperature than the slurry, however, when these streams are combined, the resulting stream temperature will be equal to the kerosene saturation temperature for the

given sulphur loading. Because the water temperature is lower than the saturation temperature, the kerosene must, prior to washing, be given sufficient heat to guarantee a wash mixture temperature that will not foster premature precipitation of the sulphur. This is conveniently attained in the heater, E-1, and at the same time ensures good dissolution characteristics. The slightly alkaline pH of the wash water is required to improve the settling properties of the ore wastes.

In the upper portion of the two compartmental settler, S-1, the washing tailings slurry and rich solvent are allowed to separate into two layers and are mildly agitated so that any emulsion formed will collapse. A scum draw-off line located at the interfacial level can be used for the removal of any persistent emulsion formed.

The underflow from this compartment falls into the lower section where the solids are concentrated to form a slurry of about 65% by weight solids. At the same time air is blown into the settled solids to aid the removal of the last traces of occluded kerosene. This is necessary as it was shown experimentally small quantities of solvent are still retained by the gangue after washing. By this treatment a pollution hazard is reduced. The thickened tailings are raked towards the central bottom discharge line and pumped, by screw pump P-3, to a tailings pond for disposal. The raking equipment is attached to the same driven shaft as the upper section agitator.

The tailings pond is, at best, the open pit left from the mining operation and could be equipped with a skimming device to collect any further disengaged solvent prior to disposing of it, preferably by

burning. In this way pollution of the environment by the solvent can be avoided.

To return to the first settler, the clarified hot water and any disengaged kerosene from the lower section is recycled to the suction side of P-2, for further washing duties.

An alternative method of separating the ore wastes from the hot solvent is also suggested by the gangue washing experiments. In this approach the solvent slurry is pumped directly into a stagnant body of water. Here the slurry solids and some associated solvent drop into the water phase. The now clarified kerosene rises through the water phase and collects as an upper liquid layer, as before. This represents the first step of the washing tests.

The tailings are then concentrated and the retained kerosene released by air blowing as previously described.

One of the possible advantages of this approach is that the water recycle loop is eliminated, thus avoiding the need for careful control to prevent emulsion formation. Emulsion formation was not observed to occur with this wash method. Any water required to make good that lost in the tailings disposal operation can be supplied directly into the lower compartment of S-1. In this way cold make-up water does not come into contact with the hot saturated kerosene.

The hot solution, leaving from the upper compartment of S-1, passes through a series of heat exchangers, E-2, being cooled by recycled cold lean solvent. After partial cooling, cold water is directly injected and intimately mixed, again by means of orifice mixers, so that

the solvent is cooled to approximately 75°F and the sulphur precipitated as fine crystals. Direct contact cooling is specified as it has been observed (55) to prevent crystal growth on vessel walls leading to blockages. By careful design, employing an approach recommended by Kern (48), this is felt not to present problems in the tubular heat exchangers as generous dirt factors can be stipulated in the design. By placing the sulphur laden solvent on the tube side, cleaning operations, should they prove to be needed, are simplified.

By employing the cold kerosene as a partial coolant for the rich solution several processing advantages are realised. A reduction in operating costs on two counts is apparent. Since heat is conserved in the preheating aspects of the exchange operation, less heat has to be supplied by the fired heater, E-1, in bringing the recycled solvent up to the extraction temperature. Also, less cooling water, to precipitate the sulphur, is needed as a result of this preheating aspect. Because the heat duty required of the fired heater is reduced, the initial capital expenditure for this item will be somewhat smaller.

The three phase mixture then enters the second settler, S-2, which again has two compartments. In the upper section the cold kerosene droplets are allowed to coalesce and form the upper liquid layer before being withdrawn and recycled. On account of the sulphur's hydrophobic nature it tends to collect at the water-kerosene interface. It will fall into the aqueous phase only after a certain amount of material has been deposited. To overcome this effect, small quantities of isopropanol can be injected at the interface. This re-

duces the surface tension causing the brimstone to descend into the water layer. In the lower section the crystallised sulphur slurry is concentrated to about 55% by weight solids, its natural limit, before being fed to a filter, F-1.

In design considerations for the settling equipment, the upper compartments can be sized by applying Stokes Law. This allows the settling velocity of the particles i.e. kerosene or water droplets, sulphur crystals and solid wastes, to be estimated. By determining the velocities of the smallest particles likely to be encountered and selecting the minimum, the most satisfactory settling area can be evaluated.

The thickener sections can be sized utilising the design data obtained in sedimentation tests by employing the classical method of Coe and Clevenger (25) augmented by the comments of Orr (61) relating to suitable safety margins and vessel heights. The sedimentation rates experimentally obtained apply to solids concentrations below those presented in this design. However, as the decreasing rate with increasing solids content shows, these figures will give a more conservative and reliable design estimate.

Because of sulphur's rapid settling characteristics a top feed rotary vacuum filter, F-1, has been specified. It was designed in accordance with the procedure outlined by Peters and Timmerhaus (63) but modified to suit this system. This is discussed in Appendix VII. The sulphur product, after being washed with water to remove the final traces of occluded kerosene and dried by air suction, is removed to a

storage area on a conveyor belt, C-2. Typically the sulphur will have a purity in excess of 99%. Plant sulphur recovery has been estimated at 99.9% and represents the recovery obtainable when the stirring is taken to equilibrium conditions and ignores the small amount of feed material that by passes the mixers.

The water, containing the solvent traces removed in the filtration operation, is mixed with the water overflow from the sulphur thickener and pumped into a separating drum, D-2. This drum is arranged so that the lighter kerosene will rise to its top. Here it is recycled, together with water forming the hot slurry wash water make-up stream to the first settler. This make-up stream supplies the water deficiency arising from water leaving the unit present in the tailings. It is this stream, having a temperature of about 70°F, that when combined with the hot water recycle from the first settler, results in the hot water wash steam being at a temperature somewhat lower than the desired extraction temperature. In this way no kerosene can leave in the water leaving D-2, which is sent to a spray pond for cooling and subsequent reuse or discharged into a natural waterway. Thus no pollution of the water resources is caused by the plant effluent streams.

The recycled cold solvent is preheated as already indicated in the heat exchangers, E-2, before being heated in a natural gas fired furnace, E-1, to a temperature of about 205°F. The hot kerosene is mixed with fresh ore and the operation repeated. Any make-up solvent required is taken from the storage tank, D-1. In all probability this tank, due to the plant's remote location, will be designed to hold

thirty days' make-up material as well as solvent contained in the mixers and heat exchangers should they be taken out of service for maintenance.

It will be noted that the plant temperatures and pressures have been kept below that of boiling water so that steam formation and vessel corrosion are minimal as stipulated by the design philosophy. However corrosion is likely to be severe in the hot slurry washing section but this can be combated to a certain extent by using a first settler constructed from wood. Similarly corrosion problems can be eliminated in the heat exchangers with all steel construction instead of the more common steel shell and copper tubes.

The foregoing outlines the processing steps required for a plant to recover the sulphur content of native ores. The description is based on experimental evidence and techniques adapted from the literature. Since an artificial ore was used to obtain some of the data used in the development of this route, the steps indicated should not be considered necessarily applicable to the Alberta ore. Further experimental verification is required with the native ore and if need be modifications to the above description made. The proposed method, however, will provide guide lines for future work. It should be emphasized that the method discussed meets the design philosophy criteria formulated at the beginning of this work.

CHAPTER VII

PLANT DESIGN CONSIDERATIONS

The preceding chapters have indicated that it is technically feasible to process the Alberta ore by a solvent extraction method. The route employed follows the guide lines set out by the design philosophy. The economic aspects of this method of sulphur recovery will be discussed in this chapter. Included in this discussion are details of the optimisation of the plant operating conditions to obtain the lowest production costs.

To aid the profitability analysis of the process a computer program was written simulating the plant described in the previous chapter. Essentially the program consists of the following parts:

- a) heat and material balance calculations,
- b) process equipment sizing,
- c) capital investment estimation, and
- d) the operating cost determination.

A summarising flow diagram of the calculation route is given in figure 14 and the complete program listing is presented in Appendix IV.

Since the material balance forms the basis for the plant evaluation, it will be discussed separately in detail in Appendix V. The other aspects of the design calculation will only be outlined, where necessary, as well known principles have, by and large, been applied. The plant capital and operating costs have been estimated using concepts described by Peters and Timmerhaus (63). Equipment cost data has been

taken mainly from work by Chilton (24) transformed by Drayer (31) into a series of equations suitable for computer analysis. The total capital investment evaluation was determined by employing plant construction parameters i.e. cost factors for erection expenses, site preparation, etc. These factors are based on the total purchased process equipment cost for a solids-fluid treating plant being constructed at a new site. Such construction parameters are presented in Chemical Engineering magazines Cost File Reviews (4). The costs obtained for the solvent extraction plant are based on 1970 construction prices. Parity between the United States and Canadian dollars has been assumed as most of the data available is published in terms of the United States currency unit.

The input data (tables 55 to 78) for this program can be divided up into four parts. The first part comprises physical data for the solvent, water and the ore. This information is taken from the books by Kern (48) and Perry (62). Specific heat and enthalpy data for sulphur is incorporated in the program as an empirical correlation using the results of Kelley (44)(45)(46) and West (77). Some of the experimental findings are also included in this first section. The next part covers the mechanical details of the processing hardware. Again Kern and Perry supply the majority of this data. Power Number data and thickener motor data are taken from references (12) and (29) respectively. Equipment cost data, not available in equation form, is taken from Aries and Newton's work (11), the book by Peters and Timmerhaus (63) and manufacturers price lists. Finally the plant design variables are given. These comprise ore, tailings and product data, certain mechanical details,

processing cost information and the desired sulphur production rate.

In establishing the optimum processing conditions for the unit, the ore sulphur content was set at a value considered representative of the deposit brimstone content. Similarly the solvent-ore slurry solids content was specified at 15% by weight i.e. the maximum value experimentally determined for satisfactory dissolution. In addition the plant sulphur production rate was maintained at 200 tons per day. This figure was used solely for optimisation purposes and does not reflect the current market demands.

The most important variables to consider in the optimisation procedure are the sulphur crystallisation temperature, the cooling water feed rate and the thickened tailings solids content. Reference to figure 13, the process flowsheet, and the following description will indicate how these parameters are influential in establishing the lowest manufacturing cost.

First consider the sulphur crystallisation temperature. If this temperature is selected too close to the cooling water feed temperature, the major part of the rich solvent cooling operation must occur in the exchangers, E-2. This results in a low log mean temperature difference since the inlet and outlet temperatures of the recycle solvent stream must be close to those of the rich solvent in order to achieve the desired amount of cooling. A low log mean temperature difference necessitates a large heat exchange area. This is expensive to install and will have a high maintenance cost. Another disadvantage with this mode of operation is the likelihood of blockages occurring through sulphur deposition in

the exchanger tubes. Thus in attempting to reduce the process heat requirement by this means, the high maintenance charges tend to offset any financial gain.

To overcome the above difficulties, raising the crystallisation temperature offers one solution. In doing this a significant decrease in the heat exchanger area requirements is observed. This not only reduces the operating costs but also the initial capital investment. However, increasing the temperature is only beneficial up to a temperature of about 75°F. Above this temperature the increased costs for process heating are not compensated for by lowered maintenance expenses.

Another way to cut the maintenance cost and initial expenditure on the exchanger, E-2, is to increase the water feed rate for cooling purposes. This approach is not as effective as the above since in cutting the maintenance charges with higher water usage, water and heating costs are increased. For limited conditions this approach is satisfactory.

Thus it can be seen that in order to determine the minimum operating expense, the sulphur crystallisation temperature and cooling water feed rate have to be optimised together. The optimum process conditions have been established with a crystallisation temperature of 73.5°F and a cooling water feed rate of 0.34 of the rich solvent volume circulation rate. By this procedure the process heat requirements have also been optimised. Table 97 summarises the calculations undertaken to determine these process conditions. The optimum case is shown in detail in tables 79 to 96. Material and heat balances, process equipment sizes

and costs, and an operating cost breakdown comprise the content of these tables.

Also important in the derivation of the most suitable operating conditions is the thickened tailings solids content. Here again, maintenance expenses are balanced against process heating charges. If the solids content of the discharged tailings from settler S-1, is low, say about 40% by weight, a large quantity of hot water will also be discharged. To replace this water in the recycled wash stream, make-up water is taken from the sulphur crystallisation section of the plant. This in turn lowers the recycle wash water temperature to below the desired extraction temperature. To ensure the solvent does not become cooled below the sulphur saturation point on washing, it is heated, in the heater, E-1, to a temperature well above the extraction temperature. The greater the amount of cold make-up water needed by the recycle wash stream, to maintain the correct water to kerosene wash ratio, the greater is the quantity of heat supplied to the solvent. With a low solids content in the ore wastes slurry, the settler area is less than that required for a slurry of high solids concentration. Capital and maintenance costs are therefore lower. Thus a balance between the settler upkeep charges and the heater gas costs must be attained. In achieving this objective the settler area and the discharged tailings solid content are optimised. This feature is also covered in the optimisation summary, table 97.

The most satisfactory pipe diameters were determined by employing the economic line size equation referred to by Peters and Timmerhaus (63). Lines carrying the slurries were also checked and recalculated where

necessary, with the correlation of Spells (74). This relates solids settling behaviour to the line size and fluid velocity.

Fluid viscosities, needed to determine pipe pressure drops, were, in all cases except one, assumed to be independent of the suspended material content. This is roughly true since the solids concentrations are relatively low. The estimated pressure drops agree quite closely with those published in the Crane Technical Paper #410 (10) for the same line sizes and flow rates. For the tailings disposal line a pressure drop was assumed as the viscosity of this slurry could not be readily estimated. The pumps were specified using the method outlined in Peters and Timmerhaus (63).

For the optimisation studies, all of the sulphur contained in the ore was assumed to be dissolved in the kerosene. This is not unreasonable since the dissolution vessel, A-1, temperature is in excess of the solvent saturation point for the given sulphur loading. The high calculated sulphur recovery stems from this fact and ignoring solids bypassing in the mixers. The other important assumption used in this study was the solvent retention capacity of the gangue. Experimentally it was found that the kerosene losses on the tailings were high. Air blowing showed that these losses could be reduced. For the optimisation study, 90% of the occluded solvent was assumed to be liberated by the washing and gas blowing operations. This constitutes the so-called best case.

In calculating the solvent extraction plant using the observed gangue solvent retention values, the annual solvent make-up cost is

found to be high, even greater than the raw material charges. This cost therefore represents the incentive to further examine the solvent gangue separation step with a view to improved operation. Even with the estimated solvent recovery arising from gas blowing the tailings, the solvent make-up charges are still a major item in the manufacturing cost determination. Therefore the objective of any future investigations should be the almost complete removal of the solvent from the ore wastes.

A case of plant operation without the partial solvent cooler, E-2, was also examined. For this situation water cooling of the hot kerosene was used entirely. Due to the high water usage, manufacturing costs again became prohibitive. Thus, the difference in water charges for this case and the optimum case indicate the advantages of installing a partial solvent cooler. However more work is perhaps necessary into the problem of sulphur blockages in the exchanger tubes. Conceivably, crystalliser design technology may provide a solution to this difficulty. The above cases are outlined in Appendix VI.

Table 95 summarises the annual operating expenses for the recovery plant. Mining and solvent costs are considered the most influential in determining the plant location. Mining costs are likely to be lowest if the unit is constructed in the deposit area. This will reduce the amount of ore transportation needed to a minimum. Typical mining costs used in this study were taken from information given by Lewis and Tisdell (51). Solvent costs can be minimised if the extraction plant is built in the Fort McMurray area. Again transportation costs are least at this location due to the proximity of a large oil production facility.

For a plant situated in the Fort Vermilion region, the only other population centre in the deposit area, delivery expenses for the solvent are high. With the kerosene losses anticipated, a delivery charge of ¢7.25 per gallon of solvent will result in prohibitive operating costs. Therefore for the optimisation study the plant was assumed to be located at Fort McMurray.

As can be seen from table 95 a manufacturing cost of \$19.68 per short ton of sulphur produced is envisaged. This is considerably higher than that quoted in the literature (5)(8) for other sulphur ore treating plants. However, a direct comparison cannot usefully be made as it is not clear on what basis the figures in the literature are given.

As suggested in the literature survey, flotation of the ore may be financially beneficial. From the comments of Bradley (17) and Lewis and Tisdell (51) it is doubtful, if, for this application, a reduction in the manufacturing expenses is possible. Difficulties in applying a flotation step to this process include drying of the concentrate before solvent extraction, sulphur losses in the flotation underflow and the need for fine grinding of the feed material.

With the current depressed sulphur prices of \$ 9.00 per short ton f.o.b.(3) and even lower, it is obvious that, at the present time, the proposed plant cannot produce brimstone at a profit. Once the demand for sulphur again increases causing a price improvement, the economic picture for this recovery route will become more favorable. Indeed other studies (59) have shown that for a 10% minimum return on investment criterion, a sulphur selling price for this type of plant, of \$38.00 per

ton f.o.b. is necessary. Thus a price increase to the 1968 level must occur again before this case can be met. When such an increase is likely to take place is difficult to predict but some forecasts indicate that it will happen within the not too distant future (27). However an increase in the amount of sulphur produced by purifying natural gas is imminent owing to recently announced gas sales. This would appear to invalidate most forecasts and prolong the current oversupply situation.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. A process capable of producing high purity elemental sulphur from the Alberta surface ore has been devised. This process uses the solvent extraction approach.
2. With the prevailing oversupply situation of brimstone and resultant low selling price, this route cannot produce sulphur for a profit.
3. Kerosene losses constitute a major factor in the production cost determination. Their reduction would be influential in lowering the sulphur manufacturing cost.

Recommendations

1. Additional development work be held in abeyance until such time as the market situation favours further feasibility studies into the economics of sulphur production.
2. Since this study employs data pertaining to a synthetic sulphur ore, any future investigations should be carried out using the actual Alberta material.
3. New work should include experiments designed to reduce the solvent losses in the plant tailings stream. Hot gas blowing of these materials offers one possible solution. The problem of heat exchanger fouling by sulphur deposition also warrants further examination. More extensive pilot plant test runs are necessary to confirm the assumption of total sulphur dissolution from the ore by the solvent.

4. The handling technique be given consideration when studying other ore bodies and solvents for exploitation. #

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NOMENCLATURE

Roman Capital Letters:

- A : settler area, ft^2
- D : impeller diameter, ft.
- N : impeller rotation speed, revolutions per second.
- N_{Re} : Reynolds number for mixing power determinations, dimensionless.
- N_{p} : Power number for mixing power determinations, dimensionless.
- U : initial liquid concentration of suspension, $\text{lbs H}_2\text{O}/\text{lb solid}$.
- V : final liquid concentration of suspension, $\text{lbs H}_2\text{O}/\text{lb solid}$.
- W : thickener feed rate, lbs_m/hr .

Roman Letters:

- g : gravitational constant, $\text{lb}_m \text{ ft}/\text{lb}_f \text{ sec}^2$.
- t_s : sampling time, seconds.
- t_{AVG} : average sampling time of all tests, seconds.
- u_c : suspension settling velocity, ft/hr .

Greek Letters:

- ρ : density, lb_m/ft^3 .
- μ : viscosity, $\text{lb}_m/\text{ft sec}$.

APPENDIX I

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SOLUBILITY CALCULATION PROGRAMS

Contained in this appendix are the program listings for the calculations used in obtaining the correction factors, for the sample weighings, and the sulphur solubility values.

MAIN and CHIEF act as calculation directors in the correction factor determinations. EXTRAP carries out the difference table calculation on data transferred from the main line program. XMORN normalises the input and extrapolated data prior to returning to the calling routine.

BOSS enables the amount of sulphur dissolved in the solvent to be calculated. The program is applicable to data obtained from the dissolution and solubility tests. Information produced by MAIN and CHIEF is utilised in this calculation procedure.

3. IF(J)=0.0

WTZERO(K)=0.0

WTTAVG(K)=0.0

WTZERO(K)=0.0

WTTAVG(K)=0.0

READ INPUT DATA

5 READ(5,6)TEMP,EMTWT,NRP,NR,TIME

6 FORM (1,2,3,4,5,6)

TEMP : SAMPLE TEMPERATURE DEG.F.

EMTWT : SAMPLE CONTAINER EMPTY WEIGHT GMS.

NRP = NUMBER OF DATA POINTS

NR : RUN NUMBER

TIME : TIME INCREMENT FOR DIFFERENCE TABLE CALCULATION SECONDS

TEMP, EMTWT, NRP, NR, TIME

DO 100 I=1, NRP

100 READ(5,6)TEMP,EMTWT,NRP,NR,TIME

101 WRITE(6,7)TEMP,EMTWT,NRP,NR,TIME

102 TIME = TIME - TIME

WTNORM(3)=P2

WTAVG(1)=1

WTAVG(2)=1

WTAVG(3)=1

DO 100 I=1,N

Y=WTNORM(1)-WTNORM(3)

IF(ABS(X).GE.ABS(Y)) GO TO 10

IF(ABS(X).GE.ABS(Y)) GO TO 10

IF(ABS(X).GE.ABS(Y)) GO TO 10

GO TO 11

10 Z=X

11 ERROR=(100.*(ABS(Z)))/WTNORM(1)

WTAVG(1)=WTAVG(1)+WTAVG(2)

YY=WTAVG(1)-WTAVG(2)

IF(ABS(X).GE.ABS(YY)) GO TO 101

IF(ABS(X).GE.ABS(YY)) GO TO 101

GO TO 111

101 ZZ=XX

111 CONTINUE

PRINT OUT RESULTS

WRITE(6,13)HR,TEMP,TIME(1),WTHQTH(1),ERRORS,WEAVER(1),P

STEP=STEP+1.

IF(STEP.GT.12.)GO TO 94

CONTINUE

GO TO 1

94 WRITE(6,95)

95 FORMAT(17X,'TABLE 1

1,28X,'SOLVENT EVAPORATION IN THE SULPHUR SOLUBILITY DETERMINATION

96 WRITE(6,115)

GO TO 1111

14 WRITE(6,15)

15 WRITE(6,115),TIME WAS

WRITE(6,95)

WRITE(6,115)

115 FORMAT(1H1

STOP

END

SUBROUTINE EXTRAP(TINC1,NBP)

THIS SUBROUTINE DETERMINES SAMPLE WEIGHTS FOR $T = 0$.
USING A DIFFERENCE TABLE APPROACH.

COMMON T(10),TIME(10),RTLDRM(3),RTZER0(1),RTTAMC(1),RTAMV(3)

SET UP DIFFERENCE TABLE

C=0.0

6 TINC=TIME(1)

7 IF(TINC.EQ.0) GO TO 9

8 IF(TINC.EQ.0) GO TO 9

9 IF(4.EQ.3) GO TO 10

10 IF(4.EQ.3) GO TO 10

11 B=-B

C=-C

12 IF(TINC.EQ.0) GO TO 13

13 IF(TINC.EQ.0) GO TO 13

14 A(I,J)=0.0

LL=0

15 DO 16 J=1,10

2 IF(TINC.GT.TIME(NBP)) GO TO 3

IF(LL.GT.4) GO TO 2

111 A(LL+2,1)=WT(I-1)-C-TINC

102 A(LL+2,1)=(WT(I-1)-C-TINC)

11-1)-C-TINC)

GO TO 201

202 A(LL+2,1)=WT(I)-R

201 LL=LL+1

TINC=TINC+TINC1

200 CONTINUE

C INTERPOLATION CALCULATIONS

3 MM=0

IF(LL.GT.4) LL=4

21 4 I=2,4

LM=LL-MM

IF(LM.EQ.1) GO TO 10

IF(LM.EQ.2)

61 A(II,I)=A(II+1,I-1)-A(II,I-1)

MM=MM+1

4 CONTINUE

10 A(1,5)=A(3,4)-A(2,4)

20 5 J=1,4

30 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 452, 453, 454, 455, 456, 457, 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 616, 617, 618, 619, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 661, 662, 663, 664, 665, 666, 667, 668, 669, 670, 671, 672, 673, 674, 675, 676, 677, 678, 679, 680, 681, 682, 683, 684, 685, 686, 687, 688, 689, 690, 691, 692, 693, 694, 695, 696, 697, 698, 699, 700, 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 785, 786, 787, 788, 789, 790, 791, 792, 793, 794, 795, 796, 797, 798, 799, 800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 821, 822, 823, 824, 825, 826, 827, 828, 829, 830, 831, 832, 833, 834, 835, 836, 837, 838, 839, 840, 841, 842, 843, 844, 845, 846, 847, 848, 849, 850, 851, 852, 853, 854, 855, 856, 857, 858, 859, 860, 861, 862, 863, 864, 865, 866, 867, 868, 869, 870, 871, 872, 873, 874, 875, 876, 877, 878, 879, 880, 881, 882, 883, 884, 885, 886, 887, 888, 889, 890, 891, 892, 893, 894, 895, 896, 897, 898, 899, 900, 901, 902, 903, 904, 905, 906, 907, 908, 909, 910, 911, 912, 913, 914, 915, 916, 917, 918, 919, 920, 921, 922, 923, 924, 925, 926, 927, 928, 929, 930, 931, 932, 933, 934, 935, 936, 937, 938, 939, 940, 941, 942, 943, 944, 945, 946, 947, 948, 949, 950, 951, 952, 953, 954, 955, 956, 957, 958, 959, 960, 961, 962, 963, 964, 965, 966, 967, 968, 969, 970, 971, 972, 973, 974, 975, 976, 977, 978, 979, 980, 981, 982, 983, 984, 985, 986, 987, 988, 989, 990, 991, 992, 993, 994, 995, 996, 997, 998, 999, 1000

WTZERO(4)=A(1,1)

WT(4,2)=5.27E-10(1-1.1E-10)=1-A(1,1) (1.1E-10=1.1E-10)

P=.0005

Q=1.0

R=1.0

S=1.0

T=1.0

U=1.0

SUBROUTINE XMORN(P,R,Q,ENTWT,M)

THIS SUBROUTINE DETERMINES THE NORMALISED SAMPLE WEIGHT.

COMMON WT(10),TIME(10),WTNORM(3),WTZERO(3),WTTAVG(3),WTAVG(3)

$R = (P - ENTWT + Q) / (WTZERO(4) - ENTWT + Q)$

RETURN

END

THIS PROGRAM ESTIMATES THE CORRECTION FACTORS
REQUIRED TO BE APPLIED TO DRIED SULPHUR SAMPLE WEIGHTS
TO ALLOW FOR SULPHUR LOSSES OCCURRING DURING DRYING.

WRITE(6,12),WTZERO(2),WTZERO(2),WTAVG(2),WTAVG(2)

TITLE PRINT OUTS

1111 WRITE(6,12)

CLEARING AREAS

1 DO 3 J=1,10

WT(J)=0.0

2 TIME(J)=0.0

3 DO 4 K=1,2

UTAVCM(1)=0.0

4 UTAVCM(1)=1.0

READ INPUT DATA

5 READ(5,*)TIME,ENTWT,NDP,AD,TIME2,TIME1

6 FORMAT(F7.1,F6.4,D13.0,F4.1)

TIME : DRYING OVEN TEMPERATURE DEG C.

ENTWT : SAMPLE CONTAINER EMPTY WEIGHT GMS.

NDP : NUMBER OF DATA POINTS

AD : AIR DRYING RATE

TIME2 : TIME INCREMENT FOR DIFFERENCE IN 15 MINUTES

TIME1 : TIME BASE MINUTES

IF(NDP.GE.50)GO TO 14

GO TO 14

7 READ(5,*)TIME(1),WT(1)

8 FORMAT(F7.1,F6.4)

TIME(1) : DRYING TIME MINUTES

WT(1) : DRIED SAMPLE WEIGHT GMS.

THIS SUBROUTINE DETERMINES SAMPLE WEIGHTS FOR T = AT
USING A DIFFERENCE TABLE APPROACH.

DIMENSION A(4,5)

COMMON WT(1:4), TIME(1:2), JTIME(1:2), ATZC(1:2), WTTAVG(1:2), WTAVG(1:2)

```

6  TIME=TIME(1)
14 IF(M.ST.3) GO TO 7
   IF(M.E.3) GO TO 8
   GO TO 9
8  R=-1
   GO TO 10
9  DO 1 J=1,4
   A(J,J)=0.0
   LL=0
   IF(M-1) 1-1,1
2  IF(TIME,GT,TIME(MD2)) GO TO 2

```


IF (I1,67,4) GO TO 2

IF ((TIME(I)-C)-TIME) 200,202,200

202 A(I1+2,I)=(WT(I-1)-P)-(WT(I-1)-WT(I))/(TIME(I-1)-TIME(I))*TIME(I)

WT(I)=A(I1+2,I)

TIME=TIME(I)

203 A(I1+2,I)=WT(I)-P

201 I1=I1+1

TIME=TIME(I)+TIME

200 CONTINUE

C

DATA I1, I2, I3

DATA I4, I5

DATA I6

DATA I7, I8, I9, I10

DATA I11, I12

61 A(I1,I)=A(I1+1,I-1)-A(I1,I-1)

4 CONTINUE

10 A(1,5)=A(3,4)-A(2,4)

DATA I1, I2, I3, I4, I5, I6, I7, I8, I9, I10

1. $f(x) = \frac{1}{x}$

2. $f(x) = \frac{1}{x^2}$

3. $f(x) = \frac{1}{x^3}$

4. $f(x) = \frac{1}{x^4}$

5. $f(x) = \frac{1}{x^5}$

6. $f(x) = \frac{1}{x^6}$

7. $f(x) = \frac{1}{x^7}$

THIS PROGRAM CALCULATES THE QUANTITY OF SOLID
 DISSOLVED PER UNIT WEIGHT OF SOLVENT FOR THE
 SOLUBILITY AND DISSOLUTION EXPERIMENTS.

PROGRAM SOLUB (114, 115, 116, 117, 118, 119)

COMMON /SOLUB/

DATA 114, 115

114 = 0.0

115 = 0.0

DO 113 M=1,10

113 READ(5,114)C(M,1),C(M,2)

114 FORMAT(57.1,50.5)

115 = 0.0

116 = 0.0

117 = 0.0

118 = 0.0

119 = 0.0

7 FORMAT(2F7.1,2F2.4)

A(I,1) : SAMPLE DRYING TIME MINUTES

A(I,2) : SOLUTION TEMPERATURE DEG.F

A(I,4) : SAMPLE SOLUTION WEIGHT GMS

A(I,5) : SAMPLE DRIED WEIGHT GMS

A(I,6) : SAMPLE CONTAINER WEIGHT GMS

SOLUBILITY CALCULATIONS

DATA

NAME

NAME

NAME

72 F=C(J,2)

GO TO 74

74 F(K,1)=(A(K,4)-A(K,5))/F

NAME

NAME

NAME

$B(K, L+4) = ((A(K, 5) - A(K, 6) + .001) / (D - E * C)) / ((A(K, 4) - A(K, 6) - .001) / E)$

DO 100 CALCULATIONS

$Y = B(I, L+2) - B(K, L+4)$

IF (ABS(Y).GT.ABS(X)) GO TO 9

$B(K, L+5) = (100. * (ABS(Z))) / (K, L+2)$

2 CONTINUE

DO 11 M=1, NED

STEP = 1. + STEP

IF (STEP.LT.10.) GO TO 11

WRITE (6, 13) I, A(NED, 2)

10 FORMAT(///, 12X, 'TABLE 1, 12, 2X, 'EQUILIBRIUM SOLUBILITY IN 450 DMSO AT', 6
16.1, 2X, '050.5.')

WRITE (6, 14)

WRITE(6,6)

STEP=1.

11 CONTINUE

WRITE(6,13) STEP

WRITE(6,14) STEP

14 FORMAT(1H1)

GO TO 1

15 STOP

APPENDIX II

REYNOLDS AND POWER NUMBER CALCULATION PROGRAM

This appendix contains the program listings required to calculate the Reynolds and Power Numbers using data obtained from the mixing experiments. The formulae 1 to 3, shown in chapter 5, are employed in the calculation.

The mainline program EXEC undertakes the calculation of the dimensionless numbers and calls ERROR and ERIC to estimate the experimental errors.

THIS PROGRAM CALCULATES THE REYNOLDS AND POWER
NUMBERS FOR THE SLURRY-KEROSENE MIXING EXPERIMENTS.

DIMENSION TM(20),PRM(20),TME(20),PME(20),TMEF(20),POWER(20)

DATA PRM, TME, PME, TMEF

COMMON MU(20),RHO(20),RHO2(20),HDE(20),DICE(20),SETH(20)

PARAMETER PRM, TME, PME, TMEF

READ INPUT DATA

600 READ(5,100)TD,BW,BT,BWC,DL,DIAIM,D,NR,IT,NOP,NT

100 FORMAT(7F9.4,2I2,2I4)

TD : TANK DIAMETER INS.

BW : BAFFLE WIDTH INS.

BT : BAFFLE THICKNESS INS.

BWC : BAFFLE WALL CLEARANCE INS.

DL : SUPERFICIAL LIQUID DEPTH INS.

DIAIM : IMPELLER DIAMETER INS.

D : DISTANCE OF IMPELLER FROM TANK BASE INS.

NB : NUMBER OF BAFFLES

IT : USER SPECIFIED TURNING TYPE IT=1 PITCHED BLADES

IT=2 STRAIGHT BLADES

NDP : NUMBER OF DATA POINTS

NT : TABLE NUMBER

IF(NT.EQ.99) GO TO 4010

101 FORMAT(3F9.4)

BLW : IMPELLER BLADE WIDTH INS.

BLT : IMPELLER BLADE THICKNESS INS.

BLL : IMPELLER BLADE LENGTH INS.

READ(5,102) ST, WTL, WTOI, WTS, BR, RT, ARM

ST : SLURRY TEMPERATURE DEG.F.

WTL : WEIGHT OF LIQUID IN TANK GMS.

WTOI : WEIGHT OF ORE IN TANK GMS.

WTS : WEIGHT OF SULPHUR IN TANK GMS.

BR : BEARING RESISTANCE LBS.

RT : ZERO R.P.M. TORQUE READING LBS.

ARM : DYNAMETER ARM LENGTH INS.


```
1105 FORMAT(3F7.1)
```

```
PP : ERROR IN WEIGHING LIQUID GMS.
```

```
RR : ERROR IN WEIGHING ORF GMS.
```

```
RRR : ERROR IN WEIGHING SULPHUR GMS.
```

```
READ(5,105)VIS,SGK,SGO,SGS
```

```
105 FORMAT(F9.2,3F9.4)
```

```
VIS : VISCOSITY OF SOLVENT AT 37 DEG.F. CPS.
```

```
SGK : SPECIFIC GRAVITY OF SOLVENT
```

```
SGO : SPECIFIC GRAVITY OF ORF
```

```
SGS : SPECIFIC GRAVITY OF SULPHUR
```

```
103 READ(5,104)TM(I),TMEF(I),RPM(I),RPMEE(I)
```

```
104 FORMAT(2F6.2,2F8.1)
```

```
TM(I) : TORQUE MEASUREMENT LBS.
```

```
TMEF(I) : TORQUE MEASUREMENT ERROR LBS.
```

```
TMEE(I) : T.M.E.
```

```
RPMEE(I) : P.P.M. ERROR
```


PRINT INPUT DATA

```

1  FORMAT(////,17X,'APPARATUS DETAILS',///,17X,'TANK DIAMETER',10X,
1.4,3X,'INS.',//,17X,'NO. OF BAFFLES',20X,12,//,17X,'BAFFLE WIDTH',
2,17X,'BAFFLE WALL CLEARANCE',11X,59.4,3X,'INS.',//,17X,'SURFICIAL
4L LIQUID DEPTH',8X,59.4,3X,'INS.',//,17X,'IMPELLER DIAMETER',
59.4,3X,'INS.',//,17X,'DISTANCE OF IMPELLER FROM',//,17X,'BOTTOM OF
6 TANK',18X,59.4,3X,'INS.',/)

```

```

IF(IT.EQ.1) GO TO 5

```

```

4  FORMAT(17X,'IMPELLER TYPE',10X,'CURVE WITH 4',/,40X,'STRAIGHT BL
1ADES',/)

```

```

GO TO 7

```

```

5  WRITE(6,6)

```

```

6  FORMAT(17X,'IMPELLER TYPE',10X,'TUBES WITH 5',/,40X,'45 DEG. BIT
1CHTD BLADES',/)

```

```

9  FORMAT(17X,'BLADE WIDTH',21X,59.4,3X,'INS.',//,17X,'BLADE THICKNES
1S',17X,59.4,3X,'INS.',//,17X,'BLADE LENGTH',20X,59.4,3X,'INS.',/)

```

```

SC=(100.*UT/ST)/(UT+WT)

```



```

      SCQ=(100.*WTS)/(WTS+WTL)

```

```

      SCQ=(100.*WTS)/(WTS+WTL)

```

```

      SCQ=(100.*WTS)/(WTS+WTL)

```

```

      GP=1.45

```

```

44 SCQ=1.0

```

```

45 TDI=DIAM/TD

```

```

      TDL=DL/TP

```

```

      WRITE(6,1)TDL,SCQ

```

```

10 FORMAT(17X,'SLURRY CONCENTRATION',/,17X,'WT. PERCENT SOLIDS',/,21X

```

```

1,'S FREE BASIS',16X,F6.1,/,/,21X,'INCLUDING SULPHUR',11X,F6.1,/,/,21

```

```

2X,'SULPHUR CONTENT OF CRF',6X,F6.1,/,/,17X,'SLURRY TEMPERATURE',14X

```

```

1,F6.1,/,/,17X,'CRF',14X,F6.1,/,/,17X,'

```

```

      WRITE(6,9)TDI,TDL

```

```

9 FORMAT(17X,'APPARATUS PARAMETERS',///,17X,'IMPELLER/TANK DIAMETER

```

```

RATIO',6X,F6.3,/,/,17X,'LIQUID DEPTH/TANK DIAMETER RATIO',2X,F6.3,/

```

```

2//)

```

```

      WRITE(6,2000)NT,SSC,ST

```

```

2000 FORMAT(17X,'TABLE',12,2X,'MIXING POWER REQUIREMENTS FOR',/,22X,F6.

```

```

11,2X,'% WT. SOLIDS KEROSENE-BLEND',/,22X,'SLURRY AT',F6.1,2X,'1000.0

```

```

2')

```

```

      WRITE(6,6004)

```

```

      DO 28 IK=1,3

```

```

      P=0.0

```

```

      S=0.0

```


PP=1.0

SG(IK)=(WTL+P)+(WTII+P)+(WTS+PP)/((WTL-P)/SGK)+((WTII-P)/SGD)+
L(WTS-PP)/SGS)

IF(IK.EQ.3) GO TO 87

88 CONTINUE

WRITE(6,101)

101 FORMAT(/////////)

WRITE(6,11)

11 FORMAT(11X,'MEASURED',3X,'SHAFT',3X,'HORSE',2X,'PERCENTAGE',2X,
'LYNOLDS',3X,'PERCENTAGE',3X,'POWER',2X,'PERCENTAGE',/,11X,'TDC',10X,
24X,'R.D.U.',2X,'POWER',5X,'RPM',1,7X,'TEMP',5X,'TEMP',5X,'TEMP',
30X,'ERRORS',/,13X,'LBS.',///)

A=1.01000

PP=0.0

$$\nabla \cdot \mathbf{A} = 0.$$
$$200 \text{ } 2047 \text{ } (K) = 0.0$$

1 = 1

HORSE POWER CALCULATION

POWER NUMBER CALCULATION

REYNOLDS NUMBER CALCULATION

IF(L.52.2) GO TO 202

TE(L.F).2) CO TO 200

$$\Gamma\Gamma\Gamma = 0.005$$

RTF=0.005

CALL HOD-1E

DO 210 KK=1,20

TME(KK)=TMEF(KK)

210 RPMF(KK)=RPMF(KK)

L=L+1

GO TO 201

202 L2=L-1

L2=L

L2=L-1

L2=L-1

DIALME=-DIALME

L=L+1

L2=L-1

200 CONTINUE

DO 400 M=1,NDB

CALL CPROD(M)

C

C PRINT OUTPUT

C

WRITE(6,500)TF(M),ZPM(M),HP(M),HPE(M),RPMF(M),TMEF(M),DME(M),DMEF(M)

1(M)

500 FORMAT(11X,F6.2,2X,F8.1,1X,F7.2,3X,F6.1,5X,F10.0,3X,F6.1,5X,F7.2,2

1X,F4.1,1X)

400 CONTINUE

WRITE(6,9997)

9997 FORMAT(/)

PRINT *,IMC,CCO,CT

603 WRITE(6,604)

604 FORMAT(1H1)

GO TO 600

END

END

SUBROUTINE ERROR(J)

COMMON HP(20),PNO(20),REFNO(20),HPS(20),PNBE(20),PENDE(20)

COMMON DUMP(20,20)

HP(J)=DUMP(J,1)

PNO(J)=DUMP(J,4)

REFNO(J)=DUMP(J,7)

CALL ERIC(J,2,ERR)

HPS(J)=ERR

CALL ERIC(J,5,ERR)

PNBE(J)=ERR

CALL ERIC(J,8,ERR)

PENDE(J)=ERR

RETURN

SUBROUTINE EFIC(JJ,KL,EF)

COMMON HP(20),DHP(20),REFD(20),HPT(20),PVDF(20),SEFICE(20)

COMMON DUMP(20,20)

X=DUMP(JJ,KL)-DUMP(JJ,KL-1)

Y=DUMP(JJ,KL)-DUMP(JJ,KL-1)

IF (ABS(X).GE.ABS(Y)) GO TO 1

1

2

3 EF=(ABS(7)*100.1/DUMP(JJ,KL-1)

RETURN

END

APPENDIX III

FILTRATION EXPERIMENT CALCULATIONS

Filtration can be described by the following equation

$$\frac{d\theta}{dV} = \frac{\mu}{Ag_c \Delta P} \left(\frac{\alpha c V}{A} + R_m \right) \quad \dots(5)$$

where A : filter area, ft^2

c : mass of particles deposited in filter per unit volume of filtrate, $\frac{\text{lb}_m}{\text{ft}^3}$

g_c : gravitational constant, $32.17 \text{ ft lb}_m/\text{lb}_f \text{ sec}^2$

R_m : filter medium resistance, ft^{-1}

V : filtrate volume, ft^3

α : specific cake resistance, ft/lb_m

θ : time, seconds

μ : viscosity $\text{lb}_m/\text{ft sec}$.

ΔP : pressure drop across filter, lb_f/ft^2

simplifying

$$\frac{d\theta}{dV} = KV + C \quad \dots(6)$$

As $\frac{d\theta}{dV}$ is constant throughout the range of experimental values, see figure 12 and table 54, K must be zero. Therefore the specific cake resistance provided by the brimstone crystals must also be zero. This implies that the cake is incompressible. Thus the only resistance to filtration comes from the filter media itself. To evaluate this para-

meter the following equation is used:

$$C = \frac{\mu R_m}{Ag_c \Delta P} \quad \dots(7)$$

Normally this is the intercept of the ordinate of a graph of equation 6. However since KV is zero, $\frac{d\theta}{dV} = C$. Therefore R_m can easily be calculated.

Calculation of R_m :

for $\Delta P = 3.9$ psi

$$\begin{aligned} R_m &= \frac{0.72 \times 28320 \times (2.65)^2 \times \pi \times 32.17 \times 3.9 \times 144}{4 \times 144 \times 1 \times .000672} \\ &= 2.10 \times 10^{10} \quad \text{ft}^{-1} \\ &= 50.4 \quad (\text{hr/ft})^2 \end{aligned}$$

for $\Delta P = 4.6$ psi

$$\begin{aligned} R_m &= \frac{0.70 \times 28320 \times (2.65)^2 \times \pi \times 32.17 \times 4.6 \times 144}{4 \times 144 \times 1 \times .000672} \\ &= 2.41 \times 10^{10} \quad \text{ft}^{-1} \\ &= 57.5 \quad (\text{hr/ft})^2 \end{aligned}$$

APPENDIX IV

COMPUTER PLANT SIMULATION PROGRAM

This appendix gives the program listings for the solvent extraction plant calculations. The program models the plant depicted in figure 13 and described in chapter VI.

The calculation procedure has been outlined in chapter VII and the overall program flowsheet shown in figure 14. The basis of the program i.e. the material balance aspects, are discussed in the following appendix.

C
C DIRECTOR

C THIS PROGRAM ACTS AS THE DIRECTOR IN THE DESIGN CALCULATION
C OF THE SOLVENT EXTRACTION UNIT.

C CALCULATION PROCEDURE FOLLOWS THE OUTLINE GIVEN IN FIGURE 14

C
COMMON H1(3),S(7),SOL(30),H2O(10),TOTAL(20),TEMP(3),TEMP2(3)

COMMON HOUTY(2),INHP(30),VIS(40),DE(40),DP1(40),TIO(40),VEL(60)

COMMON FEX(5,2),Q(20),D(12),UNB(12),OMET(11),SPHEAT(16,2),TOM(1)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),SLOPE(10),SOL1(5,2)

COMMON SOLD(25),SGSOL(25),SGH2O(25),VISCOS(25,2),CPYT(25),TEMP7(2)

COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3),SETDIA(10,2)

COMMON EQUIP(3,12,2),UNITCT(40,2),MIX(20)

COMMON POWR(6),FRACT(14),CAPIT(17),CPT(18),COSMAN(10),COSMST(10)

NN=55

WRITE(6,500)

500 FORMAT(//////////,33X,'SULPHUR RECOVERY UNIT',////////)

WRITE(6,501)

501 FORMAT(31X,'INPUT INFORMATION REQUIRED',//,35X,'FEED FLOW DIVISION')

WRITE(6,502)

502 FORMAT(1H1)

C COLLECTS PHYSICAL & MECHANICAL DESIGN DATA

CALL FISDAT(SGORE,SGSUL,CAL,NN)

CALL DATMEK(PUMPEF,DRIVEF,HEAD,FURNEF,SS,NN)

C CLEARING ARRAYS

100 DO 1 I=1,23

OI(I)=0.0

S(I)=0.0

SOL(I)=0.0

H2O(I)=0.0

TOTAL(I)=0.0

IF(I.GT.23) GO TO 1

DUMP(I)=0.1

1 TEMP(I)=0.0

INITCT(4,2)=0.0

C COLLECTS INPUT DATA

WRITE(6,502)

WRITE(6,503)

503 FORMAT(33X,'PLANT DESIGN VARIABLES')

WRITE(6,502)


```
CALL DATAIN(SCO,WCO,SOLCT,WCT,AET,SOLCS,WCS,SLURY,CT,R,T,E,F,RR,CF
,DF,IN,CIMS,RIX)
```

```
IF(SCO)99,99,101
```

```
101 CONTINUE
```

```
C MATERIAL BALANCE CALCULATIONS
```

```
C AS SHOWN IN APPENDIX V
```

```
C CALL EXTEMP(SCO,WCO,SOLCT,WCT,AET,SOLCS,WCS,SLURY,CT,SR,ET,SULT,B.
```

```
1DF,SGORE)
```

```
IF(CT)99,99,112
```

```
112 DO 11 J=9,14
```

```
IF(J.EQ.12) GO TO 12
```

```
TEMP(J)=CT
```

```
12 CONTINUE
```

```
11 CONTINUE
```

```
DO 13 K=25,26
```

```
13 TEMP(K)=CT
```

```
CALL ADD(11,12,2)
```

```
CALL ADD(2,1,3)
```

```
CALL SEIGHT(R,SOL(3),8)
```

```
CALL SEIGHT(T,S(17),15)
```

```
CALL FILTER(SCO,SULT,E,B)
```

```
CALL SUM(14)
```



```
CALL ADD(14,15,16)
CALL SUM(18)
CALL WASH(SCO,SULT,B,F)
CALL SUM(10)
CALL SUM(13)
CALL SUB(26,8,10)
CALL ADD(13,18,27)
CALL ADD(27,26,23)
CALL RATIO(RR,IT,CF)
CALL SUB(21,4,20)
CALL SUB(22,23,21)
CALL SUM(22)
CALL TWOONE(21,23)
CALL SUM(20)
CALL ADD (20,21,4)
CALL ADD (3,4,5)
CALL SUM(6)
CALL SEVEN(7,5,6)
CALL ADD(7,8,9)
H2O(25)=H2O(7)
CALL TWOONE(25,10)
CALL SEVEN(19,6,20)
H2O(24)=H2O(5)+H2O(15)
```


C STORING TEMPERATURES

C

DO 10 I=5,7

10 TEMP(I)=ET

DO 1100 K=14,23

1100 TEMP(K)=ET

TEMP(15)=TEMP(8)

TEMP(24)=TEMP(8)

C

C SCALE UP TO DESIRED THRUPUT

C

SUF=(TEMP(25)*55.352133)/S(17)

DO 50 I=1,27

OI(I)=OI(I)*SUF

S(I)=S(I)*SUF

H2O(I)=H2O(I)*SUF

SOL(I)=SOL(I)*SUF

CALL SUM(I)

50 CONTINUE

C

C HEAT BALANCE CALCULATIONS

C

CALL HEATBL

CALL HCHECK

C STREAM PHYSICAL PROPERTY CALCULATIONS

CALL RHO (SGSUL,SGORE)

CALL XMU

C EQUIPMENT SIZING

CALL PIPE(SGSUL,SGORE)

CALL DELP

CALL EXCNG(TEMP2(1),TEMP2(2),TEMP7(1),TEMP7(2),30,31,28,29,2,2,7,2
1)

CALL XMIXER(3,6,MIX,12)

CALL TANK(12,1)

CALL TANK2(2,7,22,23,27,28,29)

CALL FLOW(6,1,FL)

CALL FLOW(13,1,FEL)

CALL SET2(5,6,7,2,19,20,23,SGORE,26,FL,FEL,13)

CALL FLOW(25,2,BL)

CALL FLOW(10,2,BBL)

CALL SET2(9,25,11,4,10,26,21,SGSUL,24,BL,BBL,14)

CALL VACF(13,14,17, 11,DRIVEF,PUMPEF)

CALL FURN(FURNEF,CAL,SS,HDUTY(1),STORE(1),STORE(2))

CALL CURV(1,4,DRIVEF)

DO 97 N=1,5

97 CON(1,N)=STORE(N+2)

CALL CONV(17,10,DRIVEF)

DO 98 N=1,5

98 CON(2,N)=STORE(N+2)

CALL PUMP(1,3,3,HEAD,PUMPEF,DRIVEF,0.0,14.7,14.7)

AA=DP1(28)+DP1(29)+(((HF(23)*144.)/((DENS(28)+DENS(29))/2.))

DEAH=VOL(2,3)+VOL(3,3)

IF(DEAH.LT.HEAD)DEAH=HEAD

CALL PUMP(2,5,5,DEAH,PUMPEF,DRIVEF,AA,14.7,14.7)

CALL PUMP(3,19,19,HEAD,PUMPEF,DRIVEF,0.0,14.7,14.7)

DEEH=VOL(7,3)

IF(DEEH.LT.HEAD)DEEH=HEAD

CALL PUMP(4,23,23,DEEH,PUMPEF,DRIVEF,0.0,14.7,14.7)

P2=14.67-Q(8)

CALL PUMP(5,27,27,HEAD,PUMPEF,DRIVEF,0.0,P2,14.67)

HEED=VOL(4,3)+VOL(5,3)

IF(HEED.LT.HEAD)HEED=HEAD

CALL PUMP(6,24,24,HEED,PUMPEF,DRIVEF,0.0,14.7,14.7)

CALL PUMP(7,10,10,HEAD,PUMPEF,DRIVEF,0.0,14.7,14.7)

BB=DP1(31)+DP1(32)+(((144.)*(HF(22)+5.0))/((DENS(31)+DENS(32))/2.))

CALL PUMP(8,2,30, HEAD,PUMPEF,DRIVEF,BB,14.7,14.7)

C

C COST ESTIMATES

C

CALL OFILF(CIMS)

CALL COSTES

CALL UTIL

CALL COSTWK

C

C OUTPUT ROUTINE

C

WRITE(6,500)

WRITE(6,504)

504 FORMAT(33X,'PLANT SPECIFICATIONS')

WRITE(6,502)

CALL OUTPUT(SR,NN,FURNEF,CAL,SS)

GO TO 144

99 STOP

END

SUBROUTINE ADD(I,J,K)

C ESTIMATES INDIVIDUAL STREAM COMPONENTS BY ADDING STE-6000

C ENTERING A PIPING BRANCH TOGETHER

C COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

OI(K)=OI(I)+OI(J)

S(K)=S(I)+S(J)

H2O(K)=H2O(I)+H2O(J)

SOL(K)=SOL(I)+SOL(J)

CALL SUM(K)

RETURN

END


```
SUBROUTINE ALPHA(NT,AT,IT,JT,DX,IP,HI,RE,GT,XN)
```

```
FILM COEFF. ESTIMATION
```

```
COMMON DI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)
```

```
COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DPI(40),DOUT(40),VEL(40)
```

```
COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)
```

```
COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)
```

```
COMMON SOLD(25),SGSOL(25),SGH2O(25),VISCO(25,2),CMT(25),TEMP1(2)
```

```
COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3)
```

```
REYNOLDS NUMBER
```

```
A=TOTAL(NT)
```

```
CALL REN(A,AT,1.0000,GT)
```

```
FACT=1./2.42
```

```
CALL VISAVG(VIS(IT),VIS(JT),TMU,FACT)
```

```
CALL REN(GT,TMU,DX,RE)
```

```
JH FACTORS
```

```
IF(IP.EQ.1) GO TO 20
```

```
DO 5 I=1,50
```

```
IF(REX(I,1)-RE)5,6,7
```

```
5 CONTINUE
```



```

6 XJ=REX(I,3)
   GO TO 15
7 CALL XINTER(RE,REX(I,3),REX(I-1,3),REX(I,1),REX(I-1,1),XJ)
   GO TO 8
8 DO 21 I=1,50
   IF(REX(I,1)-RE)21,22,23
21 CONTINUE
22 XJ=REX(I,4)
   GO TO 8
23 CALL XINTER(RE,REX(I,4),REX(I-1,4),REX(I,1),REX(I-1,1),XJ)
C
C K(04)1/5 DETERMINATION
C
8 TMU=TMU/2.42
18 DO 9 K=1,50
   IF(VISN(K,1)-TMU)9,10,11
9 CONTINUE
10 FAC=VISN(K,2)
   GO TO 12
11 CALL XINTER(TMU,VISN(K,2),VISN(K-1,2),VISN(K,1),VISN(K-1,1),FAC)
12 CALL REN(FAC,DX,XJ,HI)
   IF(IP.EQ.1) GO TO 112
   CALL REN(HI,HE(3),HE(2),HIO)
   HI=HIO

```


112 RETURN

END

SUBROUTINE ARA(V,I,BBB,J)

SETTLER AREA CALCULATION

COMMON DI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),VIL(40),VEL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

BBB=(DUMP(28)*TOTAL(I))/(DENS(J)*3.14159*V)

RETURN

END


```
SUBROUTINE BETA(RN,I,J,L,GT,N,DX,P,M,XN)
```

```
C EXCHANGER PRESSURE DROP CALCULATION
```

```
COMMON DI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(30)
```

```
COMMON MDUTY(2),DUMP(30),VIS(40),SP(40),SPI(40),CIP(40),VIL(40)
```

```
COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)
```

```
COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)
```

```
COMMON SOLD(25),SGX L(25),SGH2O(25),VISGTS(25,2),COST(30),TEMP(40)
```

```
COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3)
```

```
DO 1 II=1,40
```

```
IF(REX(II,1)-RN)1,2,3
```

```
1 CONTINUE
```

```
2 E=REX(II,M)
```

```
GO TO 4
```

```
3 CALL XINTER(RN,REX(II,M),REX(II-1,M),REX(II,1),REX(II-1,1),F)
```

```
4 CALL VISAVG(DENS(I),DENS(J),GRAV,62.4)
```

```
HE(L)=(E*P*Y*[(GT**2)*E(1)]/(5.72*(10.**1)*D**E*AV)
```

```
RETURN
```

```
END
```


SUBROUTINE CELECM(X,CI,JB,EQ)

ELECTRIC MOTOR COSTS

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),DUMP(2),VIS(40),DP(40),DPI(40),DID(40),VEL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLQ(25),SGSOL(25),SOLH2O(25),VISCTS(25,2),CPYT(25),TEMP7(2)

COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3),SETDIA(10,2)

COMMON EQUIP(3,12,2),UNITCT(40,2),XMIX(20)

COST=(CI*(298.396+(25.2037*(X**.942))))/237.

CALL EFILE(COST,EQ,JB)

RETURN

END

SUBROUTINE CFILT(X,CI,JB,EQ)

C ROTARY VACUUM FILTER COST ESTIMATION

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DP2(40),VLL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLD(25),SGSOL(25),SGH2O(25),VIS(25,2),CAYT(25),TEMP7(2)

COMMON CON(2,7),HE(25),XMT(17,7),VISH(57,2),VOL(17,3),SITHIA(17,2)

COMMON EQUIP(3,12,2),UNITCT(40,2),XMIX(20)

COST=(CI*(1247.142*(X**.428)))/237.

CALL EFILE(COST,EQ,JB)

RETURN

END

SUBROUTINE CFURN(X,CI,JB,EQ)

FURNACE COST ESTIMATION

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DP2(40),VEL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLD(25),SGSOL(25),SGH2O(25),VISCOS(25,2),CRYT(25),TEMP1(25)

COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3),SETDIA(10,2)

COMMON EQUIP(3,12,2),UNITCT(40,2),XMIX(20)

COST=(CI*(2731.5+(3695.92*(X**.771))))/237.

CALL EFILE(COST,EQ,JB)

RETURN

END

SUBROUTINE CHTEX(X,CI,JB,EQ)

HEAT EXCHANGER COSTS

COMMON DI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),DUMP(20),VIS(40),DP(40),CP(40),TID(41),VEL(41)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLD(25),SSOL(25),SH2O(25),VISCOS(25,2),CRYT(25),TEMP(2)

COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3),SETDIA(10,2)

COMMON EQUIP(3,12,2),UNITCT(40,2),XMIX(20)

COST=(CI*(90.810*(X**0.573)))/237.

CALL EFILE(COST,EQ,JB)

RETURN

END

SUBROUTINE CMIXER(X,CI,JB,EQ)

MIXER COST ESTIMATION

COMMON QI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DE(40),DP(40),DIO(40),VOL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLD(25),SSOL(25),SH2O(25),VISCOS(25,2),CRYI(25),TEMPOT(2)

COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3),SETDIA(10,2)

COMMON EQUIP(3,12,2),UNITCT(40,2),XMIX(20)

COST=(CI*(117.549*(X**0.443)))/237.

CALL EFILE(COST,EQ,JB)

RETURN

END

SUBROUTINE CMOYNG(X,CI,JB,EQ,N)

SCREW PUMP COSTS

COMMON DI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DIG(40),VFL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLD(25),SGSQL(25),STH(25),VISCONS(22,2),CFMT(25),TEMPY(2)

COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3),SHTDIA(10,2)

COMMON EQUIP(7,12,2),UNITCT(40,2),XMTA(7,1)

DO 1 I=1,12

IF(EQUIP(N,I,1)-1)1,2,3

1 CONTINUE

GO TO 4

2 COST=EQUIP(N,I,2)

GO TO 5

3 IF(N.EQ.1) GO TO 2

CALL XINTER(X,EQUIP(N,I,2),EQUIP(N,I-1,2),EQUIP(N,I,1),EQUIP(N,I-1,1),COST)

GO TO 5

4 COST=EQUIP(N,I,2)*((X/EQUIP(N,I,1))**.6)

5 IF(N-2)6,7,8

6 COST=(COST*CI)/XMTA

GO TO 3

7 COST=(COST*CI)/256.

GO TO 2

8 COST=(COST*CI)/185.

9 CALL EFILE(COST,EQ,JB)

RETURN

END

SUBROUTINE CONV(I,L,EF)

CONVEYOR ESTIMATION

COMMON DI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),JDT(40),RDI(40),VEL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLD(25),SGSOL(25),SHEAT(25),VISCONS(25,2),CMT(25),TEMPT(25)

C=TOTAL(I)/2000.

DO 1 J=1,20

IF (BELT(1,J)-C) 1,2,3

3 DO 6 KK=3,5

6 CALL XINTER(C,BELT(KK,J),BELT(KK,J-1),BELT(1,J),BELT(1,J-1),STORE(1KK+4))

STORE(5)=C

STORE(6)=BELT(2,J)

GO TO 5

2 DO 4 K=5,9

4 STORE(K)=BELT(K-4,J)

GO TO 5

1 CONTINUE

5 HP(L)=(((STORE(8)*(STORE(3)/10.))+((STORE(4)/100.)*STORE(9)))*1.65
1)/EF

RETURN

END

SUBROUTINE COSTES

C

C

CAPITAL INVESTMENT ESTIMATION

C

BASED ON PURCHASED EQUIPMENT COST

C

COMMON DI(10),S(30),SOL(30),F20(30),TOTAL(20),TEMP(30),TEMP2(1)

COMMON HDUTY(1),DUMP(30),VLS(40),OP(40),DPI(40),DID(40),VFI(40)

COMMON DEX(50,4),D(20),D(12),DMR(12),FMET(13),SPHEAT(13,4),DZ(8)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLD(25),SGSOL(25),SGH2O(25),VISCOS(25,2),CRYT(25),TEMP7(2)

COMMON UN(2,7),HF(25),YNT(17,2),VLSV(50,2),VCL(10,5),SETDIA(10,2)

COMMON EDIIP(3,12,2),UNITCT(40,2),YHIX(25)

COMMON POWR(6),FRACT(14),CAPIT(17),CPT(18),COSMAN(10),COSMST(10)

CAPIT(17)=0.

DO 1 I=1,14

CAPIT(I)=UNITCT(40,2)*(FRACT(I)/FRACT(1))

CAPIT(17)=CAPIT(17)+CAPIT(I)

IF(I.EQ.9)H2(20)=CAPIT(17)

IF(I.EQ.11)CAPIT(15)=CAPIT(17)

IF(I.EQ.13)CAPIT(16)=CAPIT(17)

1 CONTINUE

RETURN

END

SUBROUTINE COSTWK

ANNUAL OPERATING COST ESTIMATE

```
COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)
```

```
COMMON HDUTY(2),DDMP(2),VIS(40),DE(40),DPI(40),CD(40),VE(40)
```

```
COMMON REX(50,8),Q(20),D(12),DNE(12),PMET(13),SPHEAT(13,2),CP(5)
```

```
COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STOPE(30),BELT(5,20)
```

```
COMMON SUD(25),SDSTL(25),SDH2O(25),VISDTS(25,2),CRXT(2,1),TEMP7(7)
```

```
COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3),SETDIA(10,2)
```

```
COMMON EQUIP(1,12,2),WUTLCT(40,2),XNEX(20)
```

```
COMMON POWR(15),FRACT(14),CAPIT(17),CPT(18),COSMAN(1,1),COSMAN(1,1)
```

RAW MATERIALS & UTILITIES

```
DO 1 I=1,5
```

```
1 CALL PRICE(CPT(I),POWR(I),CPT(17),COSMAN(I))
```

OPERATING LABOUR

```
A=365.*24.
```

```
CALL PRICE(CPT(6),POWR(6),A,COSMAN(6))
```

SUPERVISION

CALL PRICE(CPT(7),COSMAN(6),1.,COSMAN(7))

MAINTENANCE & OPERATING SUPPLIES

DO 2 IJ=8,9

2 CALL PRICE(CPT(IJ),CAPIT(16),1.,COSMAN(IJ))

LABORATORY CHARGES

CALL PRICE(CPT(10),COSMAN(6),1.,COSMAN(10))

DIRECT PRODUCTION COSTS

COSMST(1)=COSMAN(1)

DO 3 IMC=2,10

3 COSMST(1)=COSMST(1)+COSMAN(IMC)

PLANT OVERHEAD & ADMIN. EXPENSE

COSMST(2)=0.0

COSMST(3)=0.0

DO 4 IOC=2,3

DO 4 INC=6,8

4 COSMST(IOC)=COSMST(IOC)+(CPT(11,IOC)+COSMAN(IOC))

GENERAL EXPENSES

$COSMST(4) = CPT(13) * CAPIT(17)$

SUMMING CHARGES

$C = 1.1$

DO 5 ICC=1,4

5 $C = C + COSMST(ICC)$

FIXED CHARGES, SELLING COSTS & R&D EXPENSE

CALL FIXED(COSMST(5),C,CPT(14),CPT(15),CPT(16))

CALL FIXED(COSMST(6),C,CPT(15),CPT(14),CPT(16))

CALL FIXED(COSMST(7),C,CPT(16),CPT(14),CPT(15))

TOTAL PRODUCTION COST

$COSMST(8) = C$

DO 6 IBBC=5,7

6 $COSMST(8) = COSMST(8) + COSMST(IBBC)$

$COSMST(10) = 1.$

DO 7 IDC=3,7

IF(IDC.EQ.5) GO TO 7

COSMST(10)=COSMST(10)+COSMST(IDC)

7 CONTINUE

C
C ANNUAL PRODUCTION RATE

DPR=(DUMP(25)*CPT(17))/24.

C
C MANUFACTURING COST PER TON

HP(19)=(COSMST(1)+COSMST(5)+COSMST(2))/DPR

C
C PRODUCT MANUFACTURING COST PER TON

COSMST(9)=COSMST(8)/DPR

RETURN

END

SUBROUTINE CPUMP(X,CI,JB,EQ)

C

C

PUMP COSTS

C

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DP2(40),VFI(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLD(25),SOLV(25),H2O(25),VISCOS(25,2),CANN(25),TEMP(2)

COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3),SEIDIA(10,2)

COMMON EQUIP(4,12,2),UNITOT(4,2),X*IX(2)

IF(X.LE.10.00) COST=(CI*(71.124+(583.220*(X**.257))))/237.

IF(X.LE.10.00) COST=(CI*(146.780+(583.220*(X**.257))))/237.

IF(X.LE.1.00) COST=(CI*(524.444+(374.8677*X)-(195.76720*X*X)+(26.4
1551244*(X**.3))))/237.

CALL EFILE(COST,EQ,JB)

RETURN

END

SUBROUTINE CPVAL(L,M,AVG)

ESTIMATES THE SPECIFIC HEAT OF STREAM COMPONENTS

AT A GIVEN TEMPERATURE

COMMON H1(40),S1(40),SDL(40),H2(40),TOTAL(7),TEMP(4),PMET(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DIO(40),VEL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

IF(M.EQ.3) GO TO 8

IF(M.EQ.2) GO TO 7

AVG=TEMP(L)

7 TAVG=(AVG+32.0)/2.

GO TO 9

8 TAVG=AVG

9 DO 1 I=1,13

IF(PMET(I)-TAVG)1,2,3

2 DO 4 J=2,7

4 CP(J)=SPHEAT(I,J-1)

GO TO 5

3 DO 6 K=2,7

6 CALL XDITER(TAVG,SPHEAT(I,J-1),SPHEAT(I-1,J-1),PMET(I),PMET(I-1),

1CP(K))

GO TO 5

1 CONTINUE

5 CP(4)=CP(2)

C SPECIFIC HEAT OF SULPHUR EXPRESSED AS A T SERIES

C TAKEN FROM TULLER(75)

C $CP(5) = (3.63 + .0064 * (273.1 + ((TAVG - 32.0) / 1.8))) / 32.064$

RETURN

END

SUBROUTINE CSETER(X,CI,JB,EQ)

SETTLER COST ESTIMATION

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),PUMP(30),VIS(40),DP(40),DP1(40),DI(40),VEL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLID(25),SSSOL(25),SGH2O(25),VISGDS(25,2),CRYT(25),TEMP7(2)

COMMON CON(2,7),HE(25),XNT(17,2),VISN(53,2),VOL(10,3),SRTOIA(1,7)

COMMON EQUIP(3,12,2),UNITCT(40,2),XMIX(20)

COST=(CI*(498.290*(X**1.059)))/237.

CALL EFILE(COST,EQ,JB)

RETURN

END


```
SUBROUTINE CTANK(X,CI,JB,FQ)
```

```
TANK COST ESTIMATION FROM CHILTON(24) & DRAYER(1)
```

```
COMMON DI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)
```

```
COMMON HDUTY(2),DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)
```

```
COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)
```

```
COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)
```

```
COMMON SOLD(25),SGSOL(25),SGH2O(25),VISCOS(25,2),CPYT(25),TEMP7(2)
```

```
COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3),SETDIA(10,2)
```

```
COMMON EQUIP(3,12,2),UNITCT(40,2),XMIX(20)
```

```
COST=(CI*(21.029*(X**.533)))/237.
```

```
CALL EFILE(COST,FQ,JB)
```

```
RETURN
```

```
END
```



```

SUBROUTINE DATAIN (SCO,WCO,SOLCT,WCT,AET,SOLCS,WCS,SLURY,CT,R,T,E
1,F,RR,CF,DF,NN,CIMS,MIX)

```

```

C THIS SUB PROGRAM READS THE DESIGN VARIABLES
C FOR THE PLANT DESIGN
C

```

```

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)
COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DIO(40),VEL(40)
COMMON REX(50,2),Z(20),Z1(20),DPR(12),PDET(13),SPHEAT(13,2),CF(8)
COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)
COMMON SOLD(25),SGSOL(25),SGH2O(25),VISCOS(25,2),CRYT(25),TEMP7(2)
COMMON CON(2,7),HE(25),ENT(17,2),VISH(5,2),VEL(1,2),SETHA(10,2)
COMMON EQUIP(3,12,2),UNITCT(40,2),XMIX(20)
COMMON POWR(6),FRACT(14),CAPIT(17),CPT(18),COSMAN(10),COSMST(10)

```

```

C PLANT DESIGN INFORMATION READ IN
C

```

```

READ(5,1)SCO,WCO,SOLCT,WCT,SOLCS,WCS,F,P

```

```

1 FORMAT(8F7.4)

```

```

C SCO : SULPHUR CONTENT OF ORE
C WCO : WATER CONTENT OF ORE
C SOLCT : SOLVENT CONTENT OF TAILINGS
C WCT : WATER CONTENT OF TAILINGS
C SOLCS : SOLVENT CONTENT OF PRODUCT

```


C WCS : WATER CONTENT OF PRODUCT
 C E : SOLVENT OCCCLUDED ON SULPHUR AFTER FIRST FILTRATION
 C F : SOLVENT OCCCLUDED ON PRODUCT IN FILTER FEED

IF(SCC)1,1,1,1

101 READ(5,2)AET,CT

2 FORMAT(2F6.1)

C
 C AET : ESTIMATED EXTRACTION TEMPERATURE
 C CT : CRYSTALLISATION TEMPERATURE

READ (5,3)SLURY,R,T

3 FORMAT(F7.4,2F7.2)

C
 C SLURY : SOLVENT SOLIDS CONTENT
 C R : COOLING WATER TO RICH SOLVENT VOLUME RATIO
 C T : WASH WATER FOR SULPHUR PRODUCT RATIO

READ(5,4)TEMP(1),TEMP(12),TEMP(8)

4 FORMAT(3F6.1)

C
 C TEMP(1) : ORE FEED TEMPERATURE
 C TEMP(12): SOLVENT MAKE-UP TEMPERATURE
 C TEMP(8) : COOLING WATER TEMPERATURE

READ(5,6) RR,CF,DF

5 FORMAT(3F6.2)

RR : ORE--SOLVENT SLURRY WATER WASH VOLUME RATIO

CF : TAILINGS SOLIDS CONTENT

DF : ESTIMATED QUANTITY OF SOLVENT DISENGAGING FROM TAILINGS
DURING THICKENING

READ(5,6) DUMP(25),TOTAL(30),STORE(30)

6 FORMAT(F8.1,F6.3,F4.0)

DUMP(25) : SULPHUR DAILY PRODUCTION RATE

TOTAL(30) : SULPHUR SLURRY FILTER FEED WATER CONTENT

STORE(30) : NUMBER OF PUMP SPARKS

READ(5,6)((XMIX(I,MIX),IMIX=1,11),MIX=1,5)

7 FORMAT(F7.1,F4.0,F6.2,2F5.2,F4.0,F5.2,F4.1,2F5.2,F11.1,F5.1)

XMIX(1) : MEAN SLURRY RESIDENCE TIME IN AGITATOR

XMIX(2) : NUMBER OF MIXRES

XMIX(3) : LIQUID DEPTH/TANK DIAMETER RATIO

XMIX(4) : IMPELLER DIAMETER/TANK DIAMETER RATIO

XMIX(5) : ERROR FACTOR IN POWER NUMBER


```

C      XMIX(6) : NUMBER OF BAFFLES
C      XMIX(7) : BAFFLE WIDTH/TANK DIAMETER RATIO
C      XMIX(8) : NUMBER OF BLADES
C      XMIX(9) : BLADE WIDTH/IMPELLER DIAMETER RATIO
C      XMIX(10): IMPELLER FROM TANK BASE TO
C              IMPELLER DIAMETER RATIO
C      XMIX(11): USER SPECIFIED SCALE UP ROUTE
C              ON THE NUMBER ASSIGNED TO MIX
C      MIX      : EQUALS 1 SCALE UP AT CONSTANT REYNOLDS NUMBER
C      MIX      : EQUALS 2 SCALE UP AT CONSTANT IMPELLER TIP SPEED
C
C      READ(5,30) DUMP(21), DUMP(23), (DUMP(1P), 1P=27,30)
60  FORMAT(3F9.1,3F7.2)
C
C      DUMP(21) : SETTLING TIME IN SULPHUR THICKENER
C      DUMP(23) : SETTLING TIME IN TAILINGS THICKENER
C      DUMP(27) : MINIMUM SETTLER RESIDENCE TIME
C      DUMP(28) : SETTLER DESIGN SAFETY FACTOR
C      DUMP(29) : MINIMUM LIQUID DROPLET SIZE
C              ALLOWED IN SETTLER OUTFLOWS
C      DUMP(30) : MINIMUM SOLIDS PARTICLE SIZE
C              ALLOWED IN SETTLER OUTFLOWS
C
C      READ(5,30) (H(I), I=1,9)

```



```
20 FORMAT(1F5.1,2F5.2,2F7.4,F5.3,1F4.1,F5.1,F4.4)
```

```
C HE(1) : EXCHANGER TUBE LENGTH
```

```
C HE(2) : TUBE INSIDE DIAMETER
```

```
C HE(3) : TUBE OUTSIDE DIAMETER
```

```
C HE(4) : TUBE PITCH
```

```
C HE(5) : TUBE OUTSIDE SURFACE AREA/LIN. FT.
```

```
C HE(6) : INTERNAL TUBE FLOW AREA
```

```
C HE(7) : NUMBER OF TUBE PASSES
```

```
C HE(8) : ESTIMATED OVERALL HEAT TRANSFER COEFF.
```

```
C HE(9) : DIRT FACTOR REQUIRED
```

```
READ(5,50)(Q(IJ),IJ=5,11)
```

```
50 FORMAT(2F5.2,2F7.2,2F8.2,F5.0)
```

```
C Q(5) : FRACTION OF FILTER DRUM SUBMERGED
```

```
C Q(6) : FRACTION OF FILTER DRUM FOR AIR SUCTION
```

```
C Q(7) : DRUM ROTATION SPEED
```

```
C Q(8) : PRESSURE DROP ACROSS DRUM
```

```
C Q(9) : FILTER MEDIA RESISTANCE
```

```
C Q(10) : FILTER MEDIA RESISTANCE IN AIR SUCTION
```

```
C Q(11) : NUMBER OF FILTERS
```

```
READ(5,70)(SID(J),J=1,4)
```


20 FORMAT(2F5.0)

STORE(3) : CONVEYOR BELT VERTICAL RISE

STORE(4) : CONVEYOR BELT HORIZONTAL LENGTH

READ(5,800)(Q(I),I=1,4)

40 FORMAT(F6.1,F5.2,2F5.0)

Q(1) : SOLVENT MAKE-UP STORAGE CAPACITY

Q(2) : SOLVENT STORAGE CAPACITY SAFETY FACTOR

Q(3) : ALLOWED NUMBER OF EXCHANGERS OUT OF SERVICE

Q(4) : ALLOWED NUMBER OF MIXERS OUT OF SERVICE

READ(5,700)(CIMS)

700 FORMAT(F5.0)

CIMS : MARSHALL-STEVENSON COST INDEX

READ(5,800)(FRACT(IC),IC=1,14)

800 FORMAT(14F5.0)

PLANT COST FACTORS BASED ON PURCHASED

EQUIPMENT COSTS

C FRACT(1) : PURCHASED EQUIPMENT

C FRACT(2) : PURCHASED EQUIPMENT INSTALLATION

C FRACT(3) : INSTRUMENTATION

C FRACT(4) : PIPING

C FRACT(5) : ELECTRIC

C FRACT(6) : BUILDINGS

C FRACT(7) : YARD IMPROVEMENTS

C FRACT(8) : SERVICES

C FRACT(9) : LAND PURCHASE

C FRACT(10): ENGINEERING & SUPERVISION

C FRACT(11): CONSTRUCTION EXPENSE

C FRACT(12): CONTRACTORS FEE

C FRACT(13): CONTINGENCY

C FRACT(14): WORKING CAPITAL

C

READ(5,900)(CPT(IT),IT=1,10)

900 FORMAT(10F7.3)

READ(5,901)(CPT(ITT),ITT=11,18)

901 FORMAT(6F7.3,F6.0,F4.0)

C

C PROCESS COSTS

C

C CPT(1) : MINING COST

C CPT(2) : ELECTRICITY

CPT(3) : PROCESS WATER

CPT(4) : NATURAL GAS

CPT(5) : SOLVENT COST

CPT(6) : OPERATORS WAGE

PRODUCTION COST ITEMS

CPT(7) : SUPERVISOR

CPT(8) : MAINTENANCE

CPT(9) : OPERATING SUPPLIES

CPT(10): LABORATORY CHARGES

CPT(11): PLANT OVERHEAD

CPT(12): ADMIN. COSTS

CPT(13): INTEREST RATE

CPT(14): FIXED COSTS

CPT(15): SELLING COSTS

CPT(16): R & D CHARGES

CPT(17): NUMBER OF ONSTREAM HOURS/YEAR

CPT(18): NUMBER OF OPERATORS PER SHIFT

CLAY=1.-(SCD+WCD)

PRINTS INPUT DATA


```
WRITE(6,7)
```

```
7 FORMAT(////,19X,'DESIGN VARIABLES',///,47X,'WT. FRACTION',/,19X,'F  
1FEED',/,19X,'TYPICAL ORE COMPOSITION',///)
```

```
WRITE(6,8)SCD,CLAY,WCD,SOLCT,WCT,SOLCS,WCS
```

```
8 FORMAT(24X,'SULPHUR',19X,F6.3,/,4X,'DELAYS ETC.',16X,F6.3,/,1X,'  
1ATED',21X,F6.3,///,19X,'TAILINGS',///,24X,'SOLVENT CONTENT',11X,  
2.3,/,24X,'BONDED WATER CONTENT',6X,F6.3,///,19X,'SULPHUR PRODUCT',  
3///,24X,'SOLVENT CONTENT',11X,F6.3,/,24X,'WATER CONTENT',13X,F6.3,  
4///)
```

```
WRITE(6,9)DUMP(25)
```

```
9 FORMAT(19X,'SULPHUR PRODUCTION RATE',4X,F8.1,2X,'LS. TONS/DAY',///)
```

```
WRITE(6,10)NN
```

```
10 FORMAT(19X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',3X,'INPUT DATA')
```

```
WRITE(6,11)
```

```
11 FORMAT(1H1)
```

```
WRITE(6,12)TEMP(1),TEMP(12),TEMP(8),CT,AET
```

```
12 FORMAT(////,19X,'PROCESS TEMPERATURES',///,62X,'DEG. F.',/,19X,'O  
1FE FEED',34X,F7.1,/,19X,'SOLVENT MAKE UP',27X,F7.1,/,19X,'TAILIN  
2G WATER',29X,F7.1,///,19X,'CRYSTALLISER TEMPERATURE',18X,F7.1,/,  
319X,'ESTIMATED EXTRACTION TEMPERATURE',10X,F7.1,///)
```

```
WRITE(6,10)NN
```

```
WRITE(6,11)
```

```
WRITE(6,12)SLURRY,CF,DF
```

```
12 FORMAT(////,19X,'OTHER PARAMETERS',///,55X,'WT. FRACTION',/,19X,'
```



```

1SLURRY SOLIDS CONTENT',17X,F6.3,/,19X,'THICKENED TAILINGS SOLIDS C
2CONTENT',5X,F6.3,///,19X,'SOLVENT DISENGAGING FROM TAILINGS',/,19X,
3'DURING THICKENING - FRACTION OF',/,19X,'SOLVENT INITIALLY RETAINED
4ON SOLIDS',2X,F6.3,///)

```

```

WRITE(6,113)TOTAL(30),F,E

```

```

113 FORMAT(19X,'SULPHUR SLURRY FILTER FEED RATE',/,19X,'TAILINGS RATE',
1,F6.3,/,19X,'SOLVENT OCCLUDED ON SULPHUR AFTER',/,19X,'SETTLING
2PRIOR TO FILTERING',9X,F7.3,2X,'SULPHUR',/,19X,'SOLVENT REMAINING
3ON SULPHUR AFTER',/,19X,'FILTERING PRIOR TO WASHING WITH',/,19X,
4'WATER',13X,F6.3,2X,'SULPHUR',/)

```

```

WRITE(6,14)T,R,WB

```

```

14 FORMAT(19X,'WASH WATER FOR SULPHUR PRODUCT',2X,F6.3,2X,'SULPHUR',/
1//,54X,'VOL. FRACTION',/,19X,'COOLING WATER FOR RICH SOLVENT',8X,
2F6.3,2X,'SOLVENT',/,19X,'WASH WATER FOR SOLVENT SLURRY',/,19X,'EX
3TRACTED',20X,F6.3,2X,'SOLVENT',/////)

```

```

WRITE(6,10)NN

```

```

WRITE(6,11)

```

```

NN=NN+1

```

```

WRITE(6,81)(XMIX(IMIX),IMIX=1,10)

```

```

81 FORMAT(////,20X,'MEAN FLUID RESIDENCE TIME',13X,F7.1,2X,'MINS.',//
1,20X,'NUMBER OF MIXERS',24X,F4.1,/,20X,'LIQUID DEPTH/TANK DIAMETER
2RATIO',8X,F6.2,/,20X,'IMPELLER DIAMETER/TANK DIAMETER RATIO',4X,
3,F5.2,/,20X,'ERROR FACTOR IN POWER NUMBER',13X,F5.2,/,20X,'NUMBER
4OF Baffles',23X,F4.1,/,20X,'Baffle Width/Tank Diameter Ratio',8

```



```

5X,F5.2,/,20X,'NUMBER OF TURBINE BLADES',16X,F4.0,/,20X,'BLADE WI
6DTH/IMPELLER DIAMETER RATIO',6X,F5.2,/,20X,'IMPELLER HEIGHT FROM
7TANK BASE' ,/,20X,'TO IMPELLER DIAMETER RATIO',15X,F5.2,/)
      IF(MIX.EQ.2) GO TO 83
      WRITE(6,82)XMIX(11)
82  FORMAT(20X,'REYNOLDS NUMBER',19X,F10.0,///)
      GO TO 84
83  WRITE(6,85)XMIX(11)
85  FORMAT(20X,'IMPELLER TIP SPEED',17X,F10.0,2X,'FT/MIN',///)
84  WRITE(6,86)NN
86  FORMAT(20X,'TABLE',13,5X,'SULPHUR RECOVERY UNIT',/,33X,'MIXER DESI
IGN DATA')
      N'=N'+1
      WRITE(6,61)DUMP(30),DUMP(29),DUMP(28),DUMP(27),DUMP(23),DUMP(21)
61  FORMAT(////,16X,'MINIMUM DESIGN SOLIDS PARTICLE SIZE',/,16X,'REQUI
      IRED IN UNDERFLOW OR OVERFLOW',11X,F7.2,2X,'MM. DIA',/,16X,'MINIMU
      2M DESIGN LIQUID DROPLET SIZE',/,16X,'REQUIRED IN UNDERFLOW OR OVER
      3FLOW',11X,F7.2,2X,'MM. DIA',/,16X,'SETTLER DESIGN SAFETY FACTOR',
      416X,F7.2,/,16X,'MINIMUM RESIDENCE TIME',19X,F9.1,2X,'SECS',/,16X
      5,'SETTLING TIME TO DESIRED UNDERFLOW SOLIDS',/,16X,'CONTENT OF TAI
      6LINGS',22X,F9.1,2X,'SECS',/,16X,'SETTLING TIME TO DESIRED UNDERF
      7OW SOLIDS',/,16X,'CONTENT OF FILTER FEED',19X,F9.1,2X,'SECS',///)
      WRITE(6,62)NN
62  FORMAT(20X,'TABLE',13,5X,'SULPHUR RECOVERY UNIT',/,33X,'MIXER DESI

```


1DESIGN VARIABLES')

WRITE(6,11)

NN=NN+1

WRITE(6,31)(HE(J),J=1,9)

31 FORMAT(////,16X,'TUBE LENGTH',18X,F5.1,2X,'FT.',//,16X,'TUBE INSID
16 DIAMETER',11X,F5.3,2X,'INS.',//,16X,'TUBE OUTSIDE DIAMETER',11X,
F5.3,2X,'INS.',//,16X,'TUBE PITCH',2X,F7.4,2X,'INS.',//,16X,'OUTER
SIDE SURFACE AREA/LIN. FT.',1X,F7.4,2X,'SQ. INS./FT.',//,16X,'INTER
ANAL FLOW AREA',12X,F6.3,2X,'SQ. INS.',//,16X,'NUMBER OF TUBE PASS
55',8X,F4.0,////,16X,'ESTIMATED OVERALL HEAT',/,16X,'TRANSFER COEFF
6ICIENT',8X,F6.1,2X,'BTU/(HR)(SQ.FT)(DEG.F)',//,16X,'DIRT FACTOR RE
7QUIRED',11X,F6.3,2X,'(HR)(SQ.FT)(DEG.F)/RDT',////)

WRITE(6,32)NN

32 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,33X,'HEAT EXCHA
1NGER DESIGN DATA')

NN=NN+1

WRITE(6,51)(C(IK),IK=1,11)

51 FORMAT(////,16X,'FRACTION OF DRUM SUBMERGED',17X,F5.2,//,16X,'FRAC
TION OF DRUM FOR AIR SUCTION',11X,F5.2,//,16X,'DRUM ROTATION SPEED
2',22X,F7.2,2X,'R.P.M.',//,16X,'PRESSURE DROP ACROSS FILTER',14X,F7
3.2,2X,'PSI',//,16X,'FILTER MEDIA RESISTANCE',14X,F5.2,2X,'(HR/FT)
42 ',//,16X,'FILTER MEDIA AIR SUCTION RESISTANCE',4X,F8.2,2X,'(HR/
5FT)2 ',//,16X,'NUMBER OF FILTER UNITS',19X,F5.0,////)

WRITE(6,52)NN


```
52 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,33X,'ROTARY VAC  
1UUM FILTER DESIGN PARAMETERS')
```

```
WRITE(6,11)
```

```
NN=NN+1
```

```
WRITE(6,41)(D(IP),IP=1,4)
```

```
41 FORMAT(////,19X,'OTHER PARAMETERS',///,19X,'SOLVENT LOSS',/,19X,  
1,'STORAGE CAPACITY',16X,F6.1,2X,'DAYS',//,19X,'OVERDESIGN FACTOR F  
2OR',/,19X,'STORAGE CAPACITY',18X,F5.2,//,19X,'MAXIMUM NUMBER OF MI  
XERS',/,19X,'OUT OF SERVICE',2X,F3.0,2X,'UNITS',//,19X,'MAXIMUM N  
4UMBER OF HEAT',/,19X,'EXCHANGERS OUT OF SERVICE',9X,F3.0,2X,'UNITS  
5'////)
```

```
WRITE(6,29)STORE(30)
```

```
29 FORMAT(19X,'ALL PUMPING EQUIPMENT IS SPARED',/,19X,'WITH',28X,F5.0  
1,2X,'EXTRA UNIT',///)
```

```
WRITE(6,701)CIMS
```

```
701 FORMAT(19X,'MARSHALL-STEVENSON COST INDEX',/,19X,'FOR 1970',24X,F5.0  
1,///)
```

```
WRITE(6,702)NN
```

```
702 FORMAT(19X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',3X,'MISCELLANEOUS  
1 DATA')
```

```
WRITE(6,11)
```

```
NN=NN+1
```

```
WRITE (6,2000)(CPT(IJID),IJID=1,5),CPT(17),CPT(18),CPT(6)
```

```
2000 FORMAT(////,12X,'RAW MATERIALS AND UTILITIES',///,14X,'TOTAL COST
```



```

1',21X,F6.2,2X,'$/TON USE',//,14X,'ELECTRICITY',21X,F7.3,2X,'$/KWH'
2',//,14X,'PROCESS WATER',19X,F7.3,2X,'$/M USG',//,14X,'NATURAL GAS'
3',21X,F7.3,2X,'$/M USE',//,14X,'SOLVENT MAKE-UP',11X,F7.3,2X,'$/M'
4G',///,12X,'OPERATING LABOUR',///,14X,'NUMBER OF ON-STREAM HOURS',
55X,F6.0,2X,'HOURS/YEAR',//,14X,'NUMBER OF OPERATORS PER SHIFT',3X,
6F4.0,//,14X,'OPERATORS WAGE',18X,F6.2,2X,'$/HR',///)

```

```
WRITE(6,2001)NN
```

```

2001 FORMAT(19X,'TABLE',15,5X,'SULPHUR RECOVERY UNIT',3X,'PROCESSING CO
1ST DETAILS')

```

```
WRITE(6,11)
```

```
MM=0.1
```

```
WRITE(6,2002)(CPT(10)),12JP=7,14)
```

```

2002 FORMAT(////,12X,'PRODUCTION COST ITEMS',///,14X,'SUPERVISION',18X,
1F4.2,2X,'FRACTION OF OPERATING LABOUR',//,14X,'MAINTENANCE',18X,F4
2.2,2X,'FRACTION OF FIXED CAPITAL',//,14X,'OPERATING SUPPLIES',11X,
3F4.2,2X,'FRACTION OF FIXED CAPITAL',//,14X,'LABORATORY CHARGES',11
4X,F4.2,2X,'FRACTION OF OPERATING LABOUR',//,14X,'PLANT OVERHEAD',1
55X,F4.2,2X,'FRACTION OF OPERATING LABOUR',//,49X,'SUPERVISION AND MAI
6MAINTENANCE',//,14X,'ADMINISTRATION COST',10X,F4.2,2X,'FRACTION OF
7 OPERATING LABOUR',//,49X,'SUPERVISION AND MAINTENANCE',//,14X,'IN
8TEREST RATE',10X,F4.2,2X,'% CHARGED ON TOTAL CAPITAL',//,14X,'FRIE
9D COSTS',18X,F4.2,2X,'FRACTION OF DIRECT COSTS',/)

```

```
WRITE (6,2003)CPT(15),CPT(16)
```

```

2003 FORMAT(14X,'SELLING COSTS',18X,F4.2,2X,'FRACTION OF DIRECT COSTS',

```



```
1//,14X,'RESEARCH AND DEVELOPMENT',5X,F4.2,2X,'FRACTION OF DIRECT C  
2OSTS',///)
```

```
WRITE(6,2001)NN
```

```
WRITE(6,11)
```

```
NN=NN+1
```

```
100 RETURN
```

```
END
```



```
SUBROUTINE DATMEK(PUMPEF,DRIVEF,HEAD,FURNEF,SSS,NN)
```

```
C THIS SUBPROGRAM READS IN THE MECHANICAL DATA
```

```
COMMON DI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)
```

```
COMMON HOUTY(2),PUMP(30),VIS(40),OP(4,1),DPT(4,1),T(4,1),VAL(6,1)
```

```
COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)
```

```
COMMON DENS(40),HTDFT(40),CAP(13),HF(20),STGHT(3,1),T2(2,1),DST
```

```
COMMON SOLC(25),SOSOL(25),WH2O(25),VISCONS(5,2),TLY(2,1),TEMP(2)
```

```
COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3),SETDIA(10,2)
```

```
COMMON EQUIP(3,12,2),UNITCT(40,2),XMIX(20)
```

```
WRITE(6,100)
```

```
100 FORMAT(//////////,31X,'MECHANICAL DESIGN PARAMETERS')
```

```
WRITE(6,13)
```

```
DO 1 JJ=1,17
```

```
1 READ(5,31)(XNT(JJ,L),L=1,2)
```

```
31 FORMAT(F8.2,F6.0)
```

```
C XNT(JJ,1) : SHELL DIAMETER
```

```
C XNT(JJ,2) : NUMBER OF TUBES IN SHELL
```

```
DO 70 JR=1,50
```

```
70 READ(5,71)(VISN(JR,100),L=1,10),(REX(JR,NT),NT=1,8)
```

```
71 FORMAT(F5.1,F7.3,F10.0,F7.4,2F6.1,F9.6,F8.5)
```



```

C      VISN(JR,1) : SOLVENT VISCOSITY
C      VISN(JR,2) : SOLVENT W(PR)1/3 VALUE
C      REX(JR,1) : REYNOLDS NUMBER
C      REX(JR,2) : COMMERCIAL PIPE FRICTION FACTOR
C      REX(JR,3) : JH FACTOR TUBE SIDE
C      REX(JR,4) : JH FACTOR SHELL SIDE
C      REX(JR,5) : FRICTION FACTOR EXCHANGER TUBES
C      REX(JR,6) : FRICTION FACTOR EXCHANGER SHELL
C

```

```

      DO 500 IPN=1,20
500  READ(5,501)(REX(IPN,IP),IP=7,8)
501  FORMAT(F10.0,F5.1)
C

```

```

C      REX(IPN,7) : REYNOLDS NUMBER
C      REX(IPN,8) : POWER NUMBER
C

```

```

      DO 300 IMS=1,10
300  READ(5,301)(SETDIA(IMS,LMS),LMS=1,2)
301  FORMAT(F6.0,F6.2)
C

```

```

C      SETDIA(IMS,1) : THICKENER DIAMETER
C      SETDIA(IMS,2) : THICKENER MOTOR HORSE POWER
C

```

```

      READ(5,5) PUMPEE,DRIVEE,HEAD

```



```
5 FORMAT(2F5.2,F6.1)
```

```
C  
C PUMPEF : PUMP EFFICIENCY
```

```
C DRIVEF : ELECTRIC MOTOR EFFICIENCY
```

```
C HEAD : PIPE TRACK ELEVATION
```

```
READ(5,6)FURNEF,SSS
```

```
6 FORMAT(2F7.2)
```

```
C  
C FURNEF : FURNACE EFFICIENCY
```

```
C SSS : STOICHIOMETRIC AIR REQUIREMENT
```

```
C  
DO 299 IEQ=1,12
```

```
299 READ(5,350)((EQUIP(NEQ,IEQ,LEQ),LEQ=1,2),NEQ=1,3)
```

```
350 FORMAT(3(F7.1,F7.0))
```

```
C  
C EQUIP(1,IEQ,1) : SCREW PUMP SIZE
```

```
C EQUIP(1,IEQ,2) : SCREW PUMP COST
```

```
C EQUIP(2,IEQ,1) : VACUUM PUMP SIZE
```

```
C EQUIP(2,IEQ,2) : VACUUM PUMP COST
```

```
C EQUIP(3,IEQ,1) : CONVEYOR BELT LENGTH
```

```
C EQUIP(3,IEQ,2) : CONVEYOR BELT COST
```

```
C  
WRITE(5,12)
```



```
32 FORMAT(////,25X,'SHELL I.D. INS.',8X,'TUBE COUNT',/,48X,'ONE PAS
1S',//)
```

```
DO 33 JK=1,17
```

```
33 WRITE(6,34)(XNT(JK,L),L=1,2)
```

```
14 FORMAT(17X,F6.2,15X,F6.3)
```

```
WRITE(6,38)
```

```
38 FORMAT(////,20X,'DATA FOR 3/4 IN. O.D. TUBES',/,20X,'ON 15/16 IN.
1TRIANGULAR PITCH',//)
```

```
WRITE(6,35)NN
```

```
35 FORMAT(20X,'TABLE',13,5X,'SULPHUR RECOVERY UNIT',3X,'TUBE SHEET LA
1YOUT')
```

```
NN=NN+1
```

```
WRITE(6,13)
```

```
13 FORMAT(1H1)
```

```
WRITE(6,14)
```

```
14 FORMAT(////,19X,'NOMINAL PIPE SIZE',10X,'INTERNAL DIAMETER',/,25X
1,'INS.',23X,'INS.',//)
```

```
DO 3 J=1,12
```

```
READ(5,4)DNB(J),D(J)
```

```
4 FORMAT(F6.1,F8.3)
```

C

C DNB(J) : PIPE NOMINAL BORE SIZE

C D(J) : PIPE DIAMETER

C


```

3  WRITE(6,15)DNB(J),D(J)
15  FORMAT(23X,F6.1,11X,F3.3)
    WRITE(6,19)
19  FORMAT(//////)
    WRITE(6,16)NN
16  FORMAT(20X,'TABLE',13,5X,'SULPHUR RECOVERY UNIT',/,33X,'STANDARD-
    1STEEL PIPE DIMENSIONS')
    WRITE(6,13)
    NN=NN+1
    WRITE(6,50)
50  FORMAT(/////,26X,'VISCOSITY',14X,'(K(PF)1/3)',/,29X,'(CPS)',1X,'(100/IN-
    150.FT.)(DEG.F./FT.)',/,,)
    DO 51 IP=1,40
51  WRITE(6,52)(VISN(IP,NP),NP=1,2)
52  FORMAT(27X,F5.1,18X,F5.3)
    WRITE(6,19)
    WRITE(6,52)NN
53  FORMAT(20X,'TABLE',13,5X,'SULPHUR RECOVERY UNIT',/,33X,'(K(PF)1/3) V
    1ALUES FOR SOLVENT')
    WRITE(6,13)
    NN=NN+1
    WRITE(6,40)
40  FORMAT(/////,25X,'REYNOLDS',12X,'JH FACTOR',/,26X,'NUMBER',6X,'TUB
    1E SIDE',5X,'SHELL SIDE',/)

```



```

DO 41 KJ=1,41
41 WRITE(6,42) (PEX(KJ,1), (PEX(KJ,1Y), 1Y=3,4)
42 FORMAT(23X,F10.0,6X,F6.1,9X,F6.1)

WRITE(6,19)

WRITE(6,43) //

43 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,33X,'HEAT TRANSFER CURVE DATA')

WRITE(6,13)

NN=NN+1

WRITE(6,36)

44 FORMAT(///,15X,'REYNOLDS',10X,'FRICTION FACTOR',/,17X,'NUMBER',13X,'COMMERCIAL PIPE',3X,'EXCHANGER TUBES',3X,'EXCHANGER SHELL',//)

DO 37 JIJ=2,43
37 WRITE(6,44) (PEX(JIJ,1), I=1,2), (PEX(JIJ,1Y), 1Y=3,4)
44 FORMAT(14X,F10.0,6X,F7.4,9X,F9.6,11X,F8.5)

WRITE(6,19)

WRITE(6,45) //

45 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,33X,'REYNOLDS NUMBER VS FRICTION FACTOR DATA')

WRITE(6,13)

NN=NN+1

WRITE(6,502)

502 FORMAT(////,20X,'REYNOLDS NUMBER',10X,'POWER NUMBER',//)

DO 503 IPIX=1,2

```



```
503 WRITE(6,504)((REX(IPNX,IPX),IPX=7,8)
```

```
504 FORMAT(22X,F10.0,15X,F5.1)
```

```
WRITE(6,19)
```

```
WRITE(6,505)NN
```

```
505 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,33X,'REYNOLDS N  
UMBER VS POWER NUMBER DATA')
```

```
WRITE(6,13)
```

```
NN=NN+1
```

```
WRITE(6,302)
```

```
302 FORMAT(////,20X,'THICKENER DIAMETER',10X,'RAKE MOTOR',/,28X,'FT',1  
17X,'HORSE POWER',//)
```

```
DO 303 IMJ=2,10
```

```
303 WRITE(6,304)((SETDIA(IMJ,LMJ),LMJ=1,2)
```

```
304 FORMAT(25X,F6.0,15X,F6.2,/) )
```

```
WRITE(6,19)
```

```
WRITE(6,305)NN
```

```
305 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,33X,'THICKENER  
RAKE MOTOR DATA')
```

```
WRITE(6,13)
```

```
NN=NN+1
```

```
WRITE(6,17)
```

```
17 FORMAT(////,18X,'BELT',7X,'BELT',7X,'BELT',5X,'HORSE POWER',5X,'HO  
RSE POWER',/,16X,'CAPACITY',5X,'WIDTH',5X,'SPEED',3X,'PER 10FT. RI  
SE',4X,'PER 100 FT.',/,15X,'S. DENSITY',5X,'INCH',6X,'FT/MIN',20X,'I
```



```
3 HORIZONTAL',/,67X,'LENGTH',///)
```

```
DO 7 J=1,4
```

```
READ(5,3)(BELT(JI,J),JI=1,5)
```

```
8 FORMAT(F7.1,F6.1,F7.1,2F7.2)
```

```
C BELT(1,J) : CONVEYOR BELT CAPACITY
```

```
C BELT(2,J) : CONVEYOR BELT WIDTH
```

```
C BELT(3,J) : CONVEYOR BELT SPEED
```

```
C BELT(4,J) : CONVEYOR MOTOR HORSE POWER FOR HORIZONTAL MOTION
```

```
C BELT(5,J) : CONVEYOR MOTOR HORSE POWER FOR VERTICAL MOTION
```

```
C
```

```
7 WRITE(6,18)(BELT(JI,J),JI=1,5)
```

```
18 FORMAT(16X,F8.1,4X,F6.1,4X,F7.1,6X,F7.2,8X,F7.2)
```

```
WRITE(6,19)
```

```
WRITE(6,20)NN
```

```
20 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,33X,'CONVEYOR D  
1 DETAILS')
```

```
NN=NN+1
```

```
WRITE(6,21)PUMPEF,DRIVEF,HEAD
```

```
21 FORMAT(////,20X,'PUMP EFFICIENCY',16X,F5.2,/,20X,'MOTOR EFFICIENC  
1Y',15X,F5.2,/,20X,'LINE ELEVATION',15X,F6.1,2X,'MFL',/)
```

```
WRITE(6,22)NN
```

```
22 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,33X,'INTERFLUANT  
1OUS DATA')
```


NN=NN+1

WRITE(6,13)

WRITE(6,298)

298 FORMAT(/////////,24X,'ADDITIONAL EQUIPMENT COST DATA')

WRITE(6,13)

WRITE(6,351)

351 FORMAT(/////,20X,'CAPACITY',10X,'PRICE',//)

WRITE(6,352)

352 FORMAT(22X,'USCMM',11X,'DOLLARS',//)

DO 353 IQE=2,11

353 WRITE(6,354)(EQUIP(1,IQE,LQE),LQE=1,2)

354 FORMAT(20X,F7.1,10X,F7.0)

WRITE(6,19)

WRITE(6,355)NN

355 FORMAT(21X,'TABLE',15,5X,'SULPHUR RECOVERY UNIT',2,33X,'SULPHUR DIOXIDE
1 COST DATA')

NN=NN+1

WRITE(6,351)

WRITE(6,356)

356 FORMAT(23X,'CMM',11X,'DOLLARS',//)

DO 357 IQQ=2,12

357 WRITE(6,354)(EQUIP(2,IQQ,LQQ),LQQ=1,2)

WRITE(6,19)

WRITE(6,358)NN


```
358 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,33X,'VACUUM PUM  
LP COST DATA')
```

```
WRITE(6,13)
```

```
NN=NN+1
```

```
WRITE(6,359)
```

```
359 FORMAT(////,21X,'LENGTH',11X,'PRICE',/,21X,'FT',11X,'DOLLARS',/)
```

```
DO 360 IQP=2,12
```

```
360 WRITE(6,354)(EQUIP(3,IQP,LQP),LQP=1,2)
```

```
WRITE(6,19)
```

```
WRITE(6,361)NN
```

```
361 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,33X,'CONVEYOR B  
ELT COST DATA')
```

```
WRITE(6,13)
```

```
NN=NN+1
```

```
101 RETURN
```

```
END
```


SUBROUTINE DELP

PRESSURE DROP CALCULATION

FOR 100 FT LENGTH OF PIPE

COMMON DI(30),S(30),SOL(30),H2O(30),TUT(30),TEMP(2),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DIO(40),VEL(40)

COMMON REX(5),R1,Q(2),D(12),QNR(12),PMET(14),SPHEAT(15),C(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),F(10),Z(2)

DO 5 J=3,32

IF(J.EQ.12) GO TO 5

IF(J.EQ.7) GO TO 5

IF(J.EQ.17) GO TO 5

IF(J.EQ.19) GO TO 6

RE=(DIO(J)*VEL(J)*DENS(J))/(12.*.000672*VIS(J))

DO 1 I=1,50

IF(IREX(I,1)-20)1,2,7

IF=REX(I,2)

GO TO 4

3 CALL XINTER(RE,REX(I,2),REX(I-1,2),REX(I,1),REX(I-1,1),EF)

GO TO 4

1 CONTINUE

4 DP1(J)=(24.*EF*(VEL(J)**2)*100.)/(32.17*DIO(J))

GO TO 7

6 DP1(J)=25.

7 DP(J)=(DP1(J)*DENS(J))/144.

5 CONTINUE

RETURN

END

SUBROUTINE DFILE(CIMS)

THIS SUBPROGRAM DIRECTS THE COST ESTIMATION

COMMON DI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TFMP2(3)

COMMON HDUTY(2),DUMP(20),VIS(40),DE(40),DP(40),DI(40),VEL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLD(25),SGSDL(25),SGH2O(25),VISCOS(25,2),CRYT(25),TEMP7(7)

COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3),SETDIA(10,2)

COMMON EQUIP(3,12,2),UNITCT(40,2),XMIX(20)

JB=1

VESSEL COSTS,D-1,D-2

CALL CTANK(VOL(1,1),CIMS,JB,1.)

JB=JB+1

CALL CTANK(VOL(7,1),CIMS,JB,1.)

SETTLER COSTS,S-1 & S-2

JB=JB+1

CALL CSETER(VOL(2,2),CIMS,JB,1.)

JB=JB+1

CALL CSETER(VOL(4,2),CIMS,JB,1.)


```

C
C   AGITATOR COSTS, A-1
C

```

```

    JB=JB+1

```

```

    CALL CMIXER(VOL(6,1),CIMS,JB,X*IX(2))

```

```

C
C   HEAT EXCHANGER COSTS, E-2
C

```

```

    JB=JB+1

```

```

    CALL CHTEX(HE(17),CIMS,JB,HE(14))

```

```

C
C   FIRED HEATER COSTS, F-1
C

```

```

    JB=JB+1

```

```

    A=HDUTY(1)/(10.**6)

```

```

    CALL CFURN(A,CIMS,JB,1.)

```

```

C
C   FILTER COSTS, F-1
C

```

```

    JB=JB+1

```

```

    CALL CFILT(Q(13),CIMS,JB,Q(11))

```

```

C
C   PUMP COSTS
C

```


B=1.+STORE(30)

DO 1 JP=1,8

JB=JB+1

IF(JP.EQ.3.OR.JP.EQ.7) GO TO 2

CALL CPUMP(HP(JP),CIMS,JB,B)

GO TO 1

2 CALL CMOYNO(CAP(JP),CIMS,JB,B,1)

1 CONTINUE

VACUUM PUMP COSTS

JB=JB+1

CALL CMOYNO(Q(14),CIMS,JB,1.,2)

COST OF CONVEYOR BELTS

DO 3 JQ=1,2

JB=JB+1

3 CALL CMOYNO(CON(JQ,2),CIMS,JB,1.,3)

ELECTRIC MOTORS

C=B

DO 4 JM=1,14

JB=JB+1

IF(JM,57.8)C=1.0000

IF(JM,72.12)C=XMIK(2)

4 CALL CELECM(HP(JM),CIMS,JB,C)

RETURN

END

SUBROUTINE DIAM(I,J,P)

C

C

CALCULATES OPTIMUM PIPE DIAMETER

C

FROM PETERS & TIMMERHAUS(63)

C

COMMON DI(30),S(30),SH(20),H2O(20),TOTAL(30),TEMP(30),TEMP2(30)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DIO(40),VEL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIORI(40),CAP(10),AP(20),STIME(30),SELI(1,20)

COMMON SOLD(25),SGSOL(25),SGH2O(25),VISCOS(25,2),CRYT(25),TEMP7(2)

R=(2.2*((TOTAL(I)/1000.)**.45))/ (DENS(J)**.2)

RETURN

END

SUBROUTINE EFILE(COST,EQUIPI,JB)

TOTAL PURCHASED EQUIPMENT COSTS

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TFMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DPI(40),DIT(40),VH(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLD(25),S6SOL(15),SCH2O(25),VISCONS(25,2),CLYT(25),TEMP1(2)

COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3),SETDIA(10,2)

COMMON EQUIP(3,12,2),UNITCT(40,2),XMIX(20)

ITEM COSTS

UNITCT(JB,1)=COST

UNITCT(JB,2)=COST *EQUIPI

ESTIMATES TOTAL EQUIPMENT COST

UNITCT(4,2)=UNITCT(4,1)+UNITCT(JB,2)

IF(JB,EO,19) UNITCT(34,2)=UNITCT(4,2)

RETURN

END


```
SUBROUTINE EXCNG(T1,T2,T3,T4,IS,JS,IT,JT,M,N,NT,MN)
```

```
C  
C HEAT EXCHANGER DESIGN AFTER KERN(48)  
C
```

```
COMMON DI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)
```

```
COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DIO(40),VFI(30)
```

```
COMMON REX(50,8),Q(20),D(12),DNB(12),PMFT(13),SPHEAT(13,2),CP(5)
```

```
COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)
```

```
COMMON SOLD(25),SOL(25),STORE(25),PTSDUS(4,2),CPVT(25),TEMP1(25)
```

```
COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3)
```

```
C  
C LMTD CALCULATION  
C
```

```
HE(16)=((T3-T2)-(T4-T1))/ALOG((T3-T2)/(T4-T1))
```

```
C  
C INITIAL AREA CALCULATION  
C
```

```
200 A=HDUTY(M)/(HE(8)*HE(16))
```

```
NNX=1
```

```
C  
C TOTAL NUMBER OF TUBES  
C
```

```
TN=A/(HE(1)*HE(1))
```

```
XT=1.0000
```

```
IF(TN.GT.XNT(17,2)) GO TO 1
```



```
4 DO 2 II=1,17
```

```
IF(XNT(II,2)-TN)2,3,3
```

```
2 CONTINUE
```

```
1 SHELL=(TN/XNT(17,2))
```

```
22 IF(SHELL-XN)21,21,20
```

```
20 XN=XN+1.00000
```

```
GO TO 22
```

```
21 TN=TN/XN
```

```
GO TO 4
```

```
3 UNEW=HDUTY(M)/(HE(16)*XNT(II,2)*HE(1)*HE(5)*XN)
```

```
C
```

```
C
```

```
TUBE SIDE CALCULATIONS
```

```
C
```

```
AT=(XNT(II,2)*HE(1))/144.
```

```
DX=HE(2)/12.
```

```
CALL ALPHA(NT,AT,IT,JT,DX,2,HIO,RET,GT,XN)
```

```
C
```

```
C
```

```
SHELL SIDE CALCULATIONS
```

```
C
```

```
BS=XNT(II,1)
```

```
AS=(XNT(II,1)*0.5*(ABS(HE(1)-HE(4)))/(144.*HE(4))
```

```
HE(25)=BS
```

```
IF(MN.EQ.1) GO TO 13
```

```
DT=(4.*((0.5*HE(4))*(0.5*HE(4))-((0.5*2.144*(0.1*(21+21)/5.))) )/G.-4
```


13.1416*HE(3)*12.)

GO TO 14

13 DET=(4.*((HE(4)**2)-((3.1416*(HE(3)**2))/4.)))/(1-1+HE(3)*12.)

14 CALL ALPHA(N,AS,IS,JS,DET,1,HI,RES,GS,XN)

PRESSURE DROP CALCULATION

CALL BETA(RET,IT,JT,23,GT,1,IX,HE(7),F,XN)

ETT=1.00000

ETA=((12.*HE(1))/HE(25))

IF(ETA-ETT) 31,31,32

ETT=ETT+1.00000

GO TO 32

31 HE(10)=ETT

DS=XNT(II,1)/12.

CALL BETA(RES,IS,JS,22,GS,10,DET,DS,6,XN)

CLEAN H/T COEFF. ESTIMATION

316 CALL UCLEAN(HIO,HI,U)

UN=-UNE

CALL UCLEAN(U,UN,U2)

U2=1./U2

IF(U,LT,UNE) GO TO 17

IF(HE(9)-U2)16,16,17

17 HE(8)=1./((1./U)+HE(9))

GO TO 200

C VISCOSITY CORRECTION

16 IF(NNX.GT.1) GO TO 216

TW=((T1+T2)/2.)+(T3-T2)/(H1H+H2))*((T3+T4-T1-T2)/2.))

CALL PHASEV(1,A,TW)

CALL VISAVG(VIS(IT),VIS(JT),COR,A)

CALL VISAVG(VIS(IS),VIS(JS),CORT,A)

COR=COR**0.14

CORT=CORT**0.14

HE(22)=HE(22)/CORT

HE(23)=HE(23)/COR

H10=H10*COR

H1=H1*CORT

NNX=NNX+1

GO TO 316

C CALCULATED DATA TO STORAGE

216 HE(18)=U

HE(14)=XN

HE(15)=HDUTY(M)/XN

HE(17)=XNT(II,2)+HE(5)*HE(1)

HE(19)=UNEW

HE(20)=HE(9)

HE(21)=U2

HE(11)=XNT(II,1)

HE(24)=XNT(II,2)

115 RETURN

END


```

SUBROUTINE EXTEMP(SCO,WCO,SOLCT,WCT,AET,SOLCS,WCS,SLURY,CT,SP,ET,S
IULT,B,DF,SGORF)

```

```

C ESTIMATES EXTRACTION TEMPERATURE TO FULLY SATURATE SOLVENT

```

```

C OVERALL MATERIAL BALANCE ALSO CALCULATED BASED ON 1LB ORE

```

```

C FEED TO UNIT SEE APPENDIX V

```

```

COMMON DI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

```

```

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DRI(40),DI(40),VEL(40)

```

```

COMMON REX(50,8),Q(20),V(12),DNR(12),PMET(13),SPHEAT(13,2),CP(5)

```

```

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

```

```

COMMON SOLP(25),SOLH(25),SOLB(25),VISCOS(25,2),CMT(25,1-47)

```

```

1 SOLID=1.-SCO

```

```

CALL SOLUB(AET,SG,3)

```

```

SLT=(SOLID*SOLCT*SG)/(SGORF*(1.-SOLCT))

```

```

CALL SOLUB(AET,SD,1)

```

```

DO 5 I=1,25

```

```

2 SULT=((SD*SLT)/(1.-SD))*(1.-DF)

```

```

SOLSP=((SCO-SULT)*SOLCS)/(1.-(SOLCS+WCS))

```

```

CALL SOLUB(CT,SD,1)

```

```

R=(1.-SD)/SD

```

```

12 TSLT=SLT*(1.-DF)

```

```

SMU=TSLT+SOLSP

```

```

Y=((1.- (SLURY*(1.+SMU))))*R)/(SLURY*(1.+R)-1.)

```

```

X=Y/R

```



```

TOT=X+SCD+Y+SMU
SD=(SCD+Y)/TOT
CALL SOLUB (ET,SD,2)
C=ABS(AET-ET)
4 IF(C.LE.1.0) GO TO 6
AET=ET
3 CONTINUE
5 WRITE(6,7)
7 FORMAT(17X,'15 ITERATIONS HAVE BEEN COMPLETED TO ITERATE EXTRACTI
ION TEMPERATURE WITHOUT CONVERGENCE THEREFORE CALCULATION HAS BEEN
STOPPED',//)
CT=-CT
GO TO 99
8 IF(CT-100.)15,14,16
16 SLUPY=SLUPY-0.1
GO TO 1
15 SP=(SCD-SOLID)/SLT
OI(1)=SOLID-WCO
S(1)=SCD
H2O(1)=WCO
CALL SUM(1)
SOL(6)=SLT
OI(6)=OI(1)
S(6)=SOLID/(1.-CF)

```


SOL (17)=SOLSP

SOL(12)=SMI

TOTAL(12)=SOL(12)

S(17)=SOD-SOLT

WZB(17)=WCS*(S(17))

CALL SUM(17)

SOL(11)=Y

S(11)=X

TOTAL(11)=X+Y

SOL(20)=SOL(6)*DF

S(21)=S(6)*DF

99 RETURN

END

SUBROUTINE FILTER(SCO,SULT,E,B)

DETERMINES FILTER STREAM MAGNITUDES

COMMON /FILT/ S(16), SOL(16), H2O(16), TOTAL(16), TEMP(16), F(16), F1(16)

SOL(16)=E*(SCO-SULT)

SOL(14)=SOL(16)

SOL(18)=SOL(16)-SOL(17)

S(18)=SOL(18)/B

S(16)=S(17)+S(18)

S(14)=S(16)

H2O(16)=H2O(15)

H2O(18)=H2O(15)

RETURN

END


```
SUBROUTINE FISOAT(SGORE,SGSUL,CAL,NN)
```

```
C THIS SUBROUTINE READS IN THE PHYSICAL DATA
```

```
C REQUIRED FOR THE PLANT DESIGN
```

```
COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),LAP(20)
```

```
COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DIO(40),VEL(40)
```

```
COMMON ALX(6,4),D(25),D(12),DPA(12),PMD(10),SPHE(10),X(1,20)
```

```
COMMON DENS(40),DIOPT(40),LAP(10),DP(20),STWEL(1),SGH2O(20)
```

```
COMMON SOLD(25),SGSOL(25),SGH2O(25),VISCOS(25,2),CRYT(25),TEMP7(2)
```

```
C READ IN DATA
```

```
WRITE(6,120)
```

```
120 FORMAT(/////////,33X,'PHYSICAL PROPERTY DATA')
```

```
WRITE(6,103)
```

```
WRITE(6,100)
```

```
100 FORMAT(/////,14X,'TEMPERATURE',1X,'SPECIFIC GRAVITY',1X,'VISCOSITY',
```

```
1 CPS',/,19X,'DEG.F.',10X,'SOLVENT WATER',8X,'SOLVENT WATER  
'',///)
```

```
DO 1 I=1,25
```

```
READ(5,2)CRYT(I),SOLD(I),SGSOL(I),SGH2O(I),(VISCOS(I,L),L=1,2)
```

```
2 FORMAT(F6.1,F9.4,2F8.4,2F6.2)
```

```
C CRYT(I) : TEMPERATURE DEG.F.
```



```

C      SOLD(I)      : SULPHUR SOLUBILITY AT CRYT(I)
C      SGSOL(I)      : SOLVENT SPECIFIC GRAVITY AT CRYT(I)
C      SGH2O(I)      : WATER SPECIFIC GRAVITY AT CRYT(I)
C      VISCOS(I,1)    : SOLVENT VISCOSITY AT CRYT(I)
C      VISCOS(I,2)    : WATER VISCOSITY AT CRYT(I)
C
1  WRITE(6,101)CRYT(I),SGSOL(I),SGH2O(I),(VISCOS(I,L),L=1,2)
101 FORMAT(19X,F6.1,8X,2F9.3,6X,2F9.2)
      DO 3 J=1,13
3  READ(5,4) PMET(J),(SPHEAT(J,K),K=1,2)
4  FORMAT(F7.1,2F9.5)
C
C      PMET(J)      : TEMPERATURE DEG.F.
C      SPHEAT(J,1): SOLVENT SPECIFIC HEAT AT PMET(J)
C      SPHEAT(J,2): WATER SPECIFIC HEAT AT PMET(J)
C
      READ(5,5)CP(1),SGSUL,SGORE,Q(12)
5  FORMAT(F10.6,2F8.4,F9.3)
C
C      CP(1)      : SPECIFIC HEAT OF DRE
C      SGSUL      : SPECIFIC GRAVITY OF SULPHUR
C      SGORE      : SPECIFIC GRAVITY OF DRE
C      Q(12)      : VISCOSITY OF AIR
C

```



```
READ(5,6)CAL,DUMP(26),DUMP(24)
```

```
6 FORMAT(F8.1,2F11.6)
```

```
C      CAL      : HEATING VALUE OF NATURAL GAS
```

```
C      DUMP(26) : SEDIMENTATION RATE OF ORE WASTES
```

```
C      DUMP(24) : SEDIMENTATION RATE OF SULPHUR SUSPENSION
```

```
WRITE(6,107)SGSUL,SGORE,Q(12)
```

```
107 FORMAT(////,20X,'SPECIFIC GRAVITY OF SULPHUR',12X,F6.2,///,20X,'SPECIFIC GRAVITY OF ORE INSOLUBLES',5X,F6.2,///,20X,'VISCOSITY OF AIR AT AMBIENT CONDITIONS',F8.3,2X,'CPS',///)
```

```
WRITE(6,102)N
```

```
102 FORMAT(20X,'TABLE',13,5X,'SULPHUR RECOVERY UNIT',/,33X,'SPECIFIC GRAVITY & VISCOSITY DATA')
```

```
WRITE(6,103)
```

```
103 FORMAT(1H1)
```

```
N=N+1
```

```
WRITE(6,104)
```

```
104 FORMAT(////,18X,'TEMPERATURE',9X,'SPECIFIC HEAT',/,21X,'DEG.F.',1,12X,'BTU/LB.DEG.F.',/,38X,'SOLVENT WATER',///)
```

```
DO 105 J=1,12
```

```
105 WRITE(6,106)PMET(J),(SPHEAT(J,K),K=1,2)
```

```
106 FORMAT(20X,F7.1,9X,2F10.5)
```

```
WRITE(6,109)CP(1)
```



```

109 FORMAT(////,20X,'SPECIFIC HEAT OF ORE INSOLUBLES',5X,F9.5,///)
      WRITE(6,108)NN
108 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,13X,'SPECIFIC H
      HEAT DATA')
      NN=NN+1
      WRITE(6,115)
115 FORMAT(////)
      WRITE(6,113)DUMP(26),DUMP(74)
113 FORMAT(20X,'SEDIMENTATION RATE OF ORE',/,20X,'INSOLUBLES',2X,11X,
      16,2X,'FT/SEC',/,20X,'SEDIMENTATION RATE OF',/,20X,'SULPHUR CRYSTA
      LLS',15X,F11.6,2X,'FT/SEC',///)
      WRITE(6,116)NN
116 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,33X,'MISCELLANE
      OUS DATA')
      WRITE(6,103)
      NN=NN+1
      WRITE(6,110)
110 FORMAT(///,20X,'TEMPERATURE',17X,'SOLUBILITY',/,23X,'DEVIATION',
      1GMS. S/GM. SOLUTION',///)
      DO 111 K=1,24
111 WRITE(6,112)CRYI(K),SOLD(K)
112 FORMAT(23X,F6.1,17X,F9.4)
      WRITE(6,115)
      WRITE(6,114)NN

```



```
114 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,33X,'SULPHUR SU  
1LUBILITY IN KEROSENE')
```

```
WRITE(6,103)
```

```
NN=NN+1
```

```
RETURN
```

```
END
```


SUBROUTINE FIXED(AP,RP,LP,OPP,EP)

AP=(OP*CP)/(1.-(LP+OPP+EP))

RETURN

END

SUBROUTINE FLOW(J,IM,FL)

SETTLER FEED & UNDERFLOW STREAM QUANTITY CALCULATION

EXPRESSED AS LBS. WATER/LBS. SOLID

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(2)

IF(IM.EQ.2) GO TO 2

1 FL=(SOL(J)+S(J)+H2O(J))/OI(J)

GO TO 3

2 FL=(SOL(J)+S(J)-S(17)+H2O(J))/S(17)

3 RETURN

END

SUBROUTINE FURN(F,C,S,H,G,A)

FURNACE CALCULATION

$G = (H * 10000.) / (C * F * S)$

$A = (2. * G * S) / 21.$

RETURN

END

SUBROUTINE HCHECK

C
C CHECKS CLOSURE OF HEAT BALANCE
C

COMMON SI(3),S(3),SOL(4),HZO(4),TOTAL(3),TEMP(4),TEMP(4)

COMMON HDUTY(2),DUMP(3),VIS(4),DP(4),DPI(4),CIN(3),VEL(4)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

AVG=32.0

R=2.21

CALL PMUD(1,1,AVG,R)

RR=0.0000

CALL PMUD(12,1,AVG,RR)

PR=32.32

CALL PMUD(8,1,AVG,PR)

PS=5.65

CALL PMUD(15,1,AVG,PS)

SA=74.28

CALL PMUD(17,1,AVG,SA)

SB=-21.21

CALL PMUD(22,1,AVG,SB)

SC=-21.21

CALL PMUD(19,1,AVG,SC)

C
C HEAT INPUT & OUTPUT
C


```
CALL HCONT(1,1)
```

```
CALL HCONT(2,23)
```

```
CALL HCONT(3,12)
```

```
CALL HCONT(4,19)
```

```
DUMP(3)=DUMP(1)+DUMP(15)
```

```
CALL HCONT(5,8)
```

```
CALL HCONT(6,17)
```

```
DUMP(7)=HDUTY(1)
```

```
DUMP(8)=0.
```

```
DO 1 I=1,7,2
```

```
1 DUMP(8)=DUMP(8)+DUMP(I)
```

```
DUMP(9)=0.0
```

```
DO 2 J=2,6,2
```

```
2 DUMP(9)=DUMP(9)+DUMP(J)
```

```
C  
C   COMPARING HEAT IN & OUT  
C
```

```
A=ABS(DUMP(8)-DUMP(9))
```

```
DUMP(10)=(100.*A)/DUMP(8)
```

```
RETURN
```

```
END
```


SUBROUTINE HCONT(I,J)

C
C HEAT CONTENT OF STREAM BASED ON 32.0 DEG.F.

C DATUM TEMPERATURE

C COMMON DI(3),S(3),SIL(3),H2O(3),IH2O(3),TEMP(3),TEMP2(3)

C COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DPI(40),DIO(40),VEL(40)

DUMP(I)=DUMP(J)*(TEMP(J)-32.0)

RETURN

END

SUBROUTINE HEAT(QR,I,K,L)

ESTIMATES HEAT REMOVED IN CRYSTALLISING SULPHUR FROM

SOLVENT IN GIVEN TEMPERATURE LIMITS

COMMON QI(3),S(2),SOL(40),H2O(40),T0(40),TEMP(40),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DIO(40),VEL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIMP(40),CAP(14),HPC(2,1),STD(14),RELT(1,2)

COMMON SOLD(25),SGSOL(25),SGH2O(25),VISCONS(25,2),CRYT(25),TEMP7(2)

ESTIMATES TOTAL HEAT REMOVED IN PPTING SULPHUR FROM

THE EXTRACTION TEMPERATURE TO THE CRYSTALLISATION TEMPERATURE

RR=0.0

T2=0.0000

QQ=0.0000

SCRY=0.0000

CALL PPTE(I,K,QQ,RR,T2,SCRY)

ESTIMATES HEAT REMOVED BY COOLING WATER

15 QW=H2O(L)*CP(3)*(TEMP(K)-TEMP(L))

ESTIMATES HEAT DUTY OF E-2

QR=QR-QW

RR=456.23

T2=0.0000

QB=0.0000

SCRY=0.0000

FINDS E-2 OUTLET TEMPERATURE

16 CALL PPTE(I,K,QB,RR,T2,SCRY)

3 E=ABS((QR-QB)/QR)

IF(E.GT..01)GO TO 16

6 TEMP7(2)=T2

21 RETURN

END

SUBROUTINE HEATBL

THIS SUBPROGRAM DIRECTS THE HEAT BALANCE CALCULATION

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DIO(40),VEL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLD(25),SGSUL(25),SGH2O(25),VISCOS(25,2),CRYT(25),TEMP7(2)

FIND TEMPERATURE OF STREAM 2,1

CALL TMIX(11,12,2,-4.65,0.00,-5.65)

TEMPC(1)=TEMP(2)

FIND TEMPERATURE OF STREAMS 16,17,18

CALL TMIX(14,15,16,4.21,5.54,12.45)

DO 1 I=17,18

1 TEMP(I)=TEMP(16)

FIND TEMPERATURE OF STREAM 27

CALL TMIX(13,18,27,-12.12,-23.1,-23.1)


```
C    FIND TEMPERATURE OF STREAMS 21,22,23
```

```
CALL TMIX(27,26,23,-12.12,-12.35,-23.4)
```

```
DO 2 J=21,22
```

```
2 TEMP(J)=TEMP(23)
```

```
C    FIND TEMPERATURE OF STREAM 4
```

```
CALL TMIX(20,21,4,-21.21,-21.35,-21.20)
```

```
C    FIND TOTAL HEAT TO BE REMOVED TO CRYSTALLISE SULPHUR IN SOLVENT
```

```
TEMP7(1)=TEMP(7)
```

```
QH=1.0000
```

```
C    HEAT DUTY OF E-2
```

```
CALL HEAT(QR,7,10,8)
```

```
HDUTY(2)=QR
```

```
C    INLET TEMPERATURE OF KEROSENE FROM E-2
```

```
P=-64.54
```

```
IN=1
```



```

      AVT=TEMP2(1)
1  CALL CPVAL(2,3,AVT)
      CALL QBTU(2,P)
      CALL QBTU4(QR,2,P)
      AVT=(TEMP2(2)+TEMP2(1))/2.
      IN=IN+1
      IF(IN.EQ.4) GO TO 4
      GO TO 3
4  PA=1.23

```

C

C DETERMINATION OF E-1 OUTLET TEMPERATURE

C

```

      AVTEMP=(TEMP(1)+TEMP(1))/2.
      CALL CPVAL(1,3,AVTEMP)
      CALL QBTU(1,PA)
      PB=-12.65
      AVT=(TEMP(6)+TEMP(2))/2.
      CALL CPVAL(2,3,AVT)
      CALL QBTU(2,PB)
      PC=-12.23
      AVT=(TEMP(6)+TEMP(4))/2.
      CALL CPVAL(4,3,AVT)
      CALL QBTU(4,PC)
      CALL HEATOC(TEMP7(1),HCRYT)

```



```

HDUTY(1)=PB*(TEMP(4)-TEMP2(1))+PA*(TEMP(4)-TEMP(1))+PC*((TEMP(1)-TEMP(4)))+(S(1)*HCRYT)
TEMP2(3)=(HDUTY(1)/PB)+TEMP2(2)

```

```

C TEMPERATURE OF STREAM 3

```

```

TEMP(2)=((HDUTY(1)-S(1)*HCRYT)/PB)+TEMP2(2)

```

```

CALL TMIX(1,2,3,12.5,-12.65,-23.32)

```

```

RETURN

```

```

END

```


SUBROUTINE HEATOC(T,DELHC)

SULPHUR HEAT OF CRYSTALLISATION CALCULATION

FROM TULLY (76)

$TCORR = ((T - 32.) / 1.8) + 273.1$

$DH = -231. + (1.82 * TCORR) - ((1.2 * TCORR ** 2) / ((10. ** 3) * 2.))$

$DELHC = (DH * 451.6) / (252. * 32.864)$

RETURN

END


```
SUBROUTINE OUTPUT(SP,NN,FB,CC,SS)
```

```
PRINT OUT ROUTINE
```

```
COMMON DI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)
```

```
COMMON HDUTY(2),DUMP(30),VIS(40),DP(10),DP2(10),DUMPA(10),VEL(10)
```

```
COMMON REX(50,8),Q(20),D(12),DNB(12),PMFT(13),SPHEAT(13,2),CP(5)
```

```
COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)
```

```
COMMON SOLID(25),SOL(5),SOLH2O(5),VIS(15,5,2),CAYE(25),TEMP(2)
```

```
COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3),SETDIA(10,2)
```

```
COMMON EQUIP(3,12,2),UNITCT(40,2),XMIX(20)
```

```
COMMON PDGR(6),FRACT(14),CAPIT(17),CPT(10),CONCENT(1),CONCENT2(1)
```

```
WRITE(6,1)
```

```
1 FORMAT(//////////,12X,'STREAM',4X,'ID',10X,'X',15X,'SOLVANT',4X,'PARAMS',  
1X,'&',5X,'SLURRY',7X,'KINETICS',/,5X,'RECYCLE',2X,'WASH WATER',3X,  
2,'WASH WATER',3X,'WATER & DRE',/,77X,'SLURRY',//,11X,'FLOWSHEET',/  
3,12X,'NUMBER',10X,'1',12X,'2',12X,'3',12X,'4',11X,'5',//)
```

```
WRITE(6,3)(S(J),J=1,5)
```

```
3 FORMAT(11X,'COMPONENT',//,12X,'SULPHUR',4X,F10.1,3X,F10.1,3X,F10.1,  
1,3X,F10.1,3X,F10.1,/) 
```

```
WRITE(6,4)(DI(K),K=1,5)
```

```
4 FORMAT(13X,'CLAYS',5X,F10.1,3X,F10.1,3X,F10.1,2X,F10.1,3X,F10.1,/) 
```

```
WRITE(6,5)(H2O(L),L=1,5)
```

```
5 FORMAT(13X,'WATER',5X,F10.1,3X,F10.1,3X,F10.1,3X,F10.1,3X,F10.1,/) 
```

```
WRITE(6,6)(SOL(M),M=1,5)
```



```
12 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',3X,'MATERIAL BALA
14CE CONTINUED')
```

```
WRITE(6,10)
```

```
WRITE(6,13)
```

```
13 FORMAT(/////////,12X,'STREAM',4X,'LEAN SOLVENT',4X,'SOLVENT',6X,'WA
15TER',0X,'WASTE',6X,'WASH WATER',/,25X,'RECYCLE',4X,'MAKE UP',5X,'T
20 PLANT',4X,'TO FILTER',4X,'EX FILTER',///,11X,'FLOWSHEET',/,12X,'
25 NUMBER',0X,'11',11X,'12',11X,'13',11X,'14',11X,'15',//)
```

```
WRITE(6,3)S(11),S(12),S(24),S(15),S(23)
```

```
WRITE(6,4)OI(11),OI(12),OI(24),OI(15),OI(23)
```

```
WRITE(6,5)H2O(11),H2O(12),H2O(24),H2O(15),H2O(23)
```

```
WRITE(6,6)SUL(11),SUL(12),SUL(24),SUL(15),SUL(23)
```

```
WRITE(6,7)TOTAL(11),TOTAL(12),TOTAL(24),TOTAL(15),TOTAL(23)
```

```
WRITE(6,8)
```

```
WRITE(6,12)NN
```

```
WRITE(6,10)
```

```
WRITE(6,14)
```

```
14 FORMAT(/////////,12X,'STREAM',6X,'WATER TO',4X,'WASH WATER',3X,'WAS
16H WATER',3X,'THICKENED',6X,'SULPHUR',/,26X,'POND',8X,'MAKE UP',6X,
21 'RECYCLE',5X,'TAILINGS',4X,'PRODUCT',///,11X,'FLOWSHEET',/,12X,'NO
26 NUMBER',0X,'16',11X,'17',11X,'18',11X,'19',11X,'20',//)
```

```
WRITE(6,3)S(22),S(21),S(20),S(19),S(17)
```

```
WRITE(6,4)OI(22),OI(21),OI(20),OI(19),OI(17)
```

```
WRITE(6,5)H2O(22),H2O(21),H2O(20),H2O(19),H2O(17)
```



```

WRITE(6,6) SOL(22), SOL(21), SOL(20), SOL(19), SOL(17)
WRITE(6,7) TOTAL(22), TOTAL(21), TOTAL(20), TOTAL(19), TOTAL(17)
WRITE(6,8)

WRITE(6,12) NN

WRITE(6,10)

WRITE(6,120)

120 FORMAT(////////,25X,'STREAM',8X,'FEED',6X,'THICKENER',7X,'WATER',/
1,36X,'TO SULPHUR',3X,'OVERFLOW',6X,'DISPOSAL',/,36X,'THICKENER',18
2X,'PUMP FEED',//,24X,'FLOWSHEET',/,25X,'NUMBER',9X,'21',11X,'22',1
3X,'23',//)
WRITE(6,140)(S(JJ),JJ=25,27)
WRITE(6,141)(OI(JK),JK=25,27)
WRITE(6,142)(H2O(JL),JL=25,27)
WRITE(6,143)(SOL(JL),JL=25,27)
WRITE(6,144)(TOTAL(JM),JM=25,27)

140 FORMAT(24X,'COMPONENT',//,25X,'SULPHUR',4X,F10.1,3X,F10.1,3X,F10.1
1,/)

141 FORMAT(26X,'CLAYS',5X,F10.1,3X,F10.1,3X,F10.1,/)
142 FORMAT(26X,'WATER',5X,F10.1,3X,F10.1,3X,F10.1,/)
143 FORMAT(25X,'SOLVENT',4X,F10.1,3X,F10.1,3X,F10.1,///)
144 FORMAT(26X,'TOTAL',5X,F10.1,3X,F10.1,3X,F10.1,///)

WRITE(6,8)

WRITE(6,2) SR

2 FORMAT(20X,'SULPHUR RECOVERY',5X,F7.3,'WT. FRACTION OF SULPHUR IN

```



```
10RE FEED',////)
```

```
WRITE(6,12)NN
```

```
WRITE(6,10)
```

```
NN=NN+1
```

```
5554 WRITE(6,15)
```

```
15 FORMAT(/////////,19X,'HEAT ENTERING PLANT',2X,'HEAT FROM SOLVENT',
```

```
1,///,12X,'STREAM',9X,'STREAM',6X,'HEAT CONTENT',6X,'STREAM',9X,'ST
```

```
2REAM',6X,'HEAT CONTENT',/,12X,'NUMBER',6X,'DESCRIPTION',6X,'BTU /
```

```
3HR',8X,'NUMBER',6X,'DESCRIPTION',6X,'BTU / HR',//)
```

```
WRITE(6,16)(DUMP(I),I=1,10)
```

```
16 FORMAT(15X,'1',3X,'ORE FEED',12X,F12.1,8X,'16',3X,'WATER TO POND',
```

```
17X,F12.1,///,14X,'12',3X,'SOLVENT MAKE UP',5X,F12.1,12X,'13',3X,'DRY
```

```
2CKENED TAILINGS',2X,F12.1,///,14X,'13',3X,'COOLING WATER',7X,F12.1,
```

```
38X,'20',3X,'SULPHUR PRODUCT',5X,F12.1,///,19X,'HEAT FROM SOLVENT',/
```

```
4,19X,'HEATER E-1',10X,F12.1,///,19X,'HEATER E-2',10X,F12.1,12X,'TOTAL',
```

```
515X,F12.1,///,19X,'HEATER E-3',10X,F12.1,12X,'TOTAL',10X,F12.1,12X,'TOTAL',
```

```
615X,F12.1,///,19X,'HEATER E-4',10X,F12.1,12X,'TOTAL',10X,F12.1,12X,'TOTAL',
```

```
WRITE(6,17)NN
```

```
17 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',3X,'HEAT BALANCE'
```

```
1)
```

```
WRITE(6,10)
```

```
NN=NN+1
```

```
WRITE(6,18)
```

```
18 FORMAT(/,19X,'STREAM',10X,'TEMPERATURE',/,19X,'FLOW SHEET',10X,'
```



```

1STREAM SECTION',/,18X,'NUMBER',9X,'1',11X,'2',11X,'3',/)
DO 19 K=1,12
  IF(K.EQ.2) GO TO 20
  IF(K.EQ.7) GO TO 21
  WRITE(6,22)K,TEMP(K)
22 FORMAT(20X,I2,8X,F7.1,/)
  GO TO 19
20 WRITE(6,23)K,(TEMP2(L),L=1,3)
23 FORMAT(20X,I2,8X,F7.1,5X,F7.1,5X,F7.1,/)
  GO TO 19
21 WRITE(6,24)K,(TEMP7(M),M=1,2)
24 FORMAT(20X,I2,8X,F7.1,5X,F7.1,/)
19 CONTINUE
  K=13
  WRITE(6,22)K,TEMP(K)
  K=K+1
  WRITE(6,22)K,TEMP(K)
  M=23
  DO 25 L=15,19
    WRITE(6,22)L,TEMP(M)
25 M=M-1
  K=21
  WRITE(6,22)K,TEMP(17)
  M=25

```



```

DO 121 MMI=21,23
WRITE(6,23)MMI,TEMP(MT)

121 MT=MT+1

WRITE(6,26)

26 FORMAT(//,20X,'ALL STREAMS ARE MEASURED IN   DEG. F.',//)

WRITE(6,27)NN

27 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,33X,'PROCESS OP
ERATING TEMPERATURES')

WRITE(6,10)

NN=NN+1

WRITE(6,70)

70 FORMAT(/,18X,'STREAM',15X,'FLUID DENSITY',/,15X,'FLOW RATE',15X
1,'STREAM SECTION',/,18X,'NUMBER',9X,'1',11X,'2',11X,'3',//)

DO 71 K=1,12

IF(K.EQ.2) GO TO 72

IF(K.EQ.7) GO TO 73

WRITE(6,74)K,DENS(K)

74 FORMAT(20X,I2,5X,F8.2,/)

GO TO 71

72 WRITE(6,75)K,(DENS(M),M=30,32)

75 FORMAT(20X,I2,5X,F8.2,4X,F8.2,4X,F8.2,/)

GO TO 71

73 WRITE(6,76)K,(DENS(I),I=27,30)

76 FORMAT(20X,I2,5X,F8.2,4X,F8.2,/)

```


71 CONTINUE

K=13

WRITE(6,74)K,DENS(21)

K=K+1

WRITE(6,74)K,DENS(15)

M=25

DO 79 J=15,19

WRITE(6,74)J,DENS(14)

79 M=M-1

K=J+1

WRITE(6,74)K,DENS(17)

KJ=21

DO 122 KK=25,27

WRITE(6,74)KJ,DENS(KK)

122 KJ=KJ+1

WRITE(6,77)

77 FORMAT(///,20X,'ALL STREAMS MEASURED IN LBS./CU. FT.',///)

WRITE(6,78)NN

78 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',3X,'STREAM DENSITIES')

WRITE(6,10)

NN=NN+1

WRITE(6,80)

80 FORMAT(////,15X,'STREAM',15X,'FLUID VISCOSITY',/,15X,'FLUID SHEET',/)


```

13X,'STREAM SECTION',/,18X,'NUMBR',9X,'1',11X,'2',11X,'3',/)
DO 81 K=2,12
  IF(K.EQ.10) GO TO 81
  IF(K.EQ.2) GO TO 82
  IF(K.EQ.7) GO TO 83
  WRITE(6,84)K,VIS(K)
84 FORMAT(20X,I2,6X,F7.2,/)
  GO TO 81
82 WRITE(6,85)K,(VIS(N),N=30,32)
85 FORMAT(20X,I2,6X,F7.2,5X,F7.2,5X,F7.2,/)
  GO TO 81
83 WRITE(6,86)K,(VIS(I),I=23,29)
86 FORMAT(20X,I2,6X,F7.2,5X,F7.2,/)
81 CONTINUE
  K=13
  WRITE(6,84)K,VIS(24)
  K=K+1
  WRITE(6,84)K,VIS(15)
  M=23
  DO 37 JJ=15,18
    WRITE(6,84)JJ,VIS(*)
87 M=M-1
  MP=21
  DO 125 K=25,27

```



```
WRITE(6,84)MP,VIS(KM)
```

```
123 MP=MP+1
```

```
WRITE(6,88)
```

```
88 FORMAT(//,20X,'ALL STREAMS MEASURED IN CPS.',//)
```

```
WRITE(6,89)NN
```

```
89 FORMAT(20X,'TABLE',13,5X,'SULPHUR RECOVERY UNIT',3X,'STERILIZATION  
UNITIES')
```

```
WRITE(6,10)
```

```
NN=NN+1
```

```
WRITE(6,200)(XMIX(IM),IM=1,2),(VOL(6,MV),MV=1,3),XMIX(19),HP(12)
```

```
200 FORMAT(////,20X,'MEAN FLUID RESIDENCE TIME',13X,F7.1,2X,'MINS',//,  
120X,'NUMBER OF MIXERS',24X,F4.0,//,20X,'MIXER VOLUME',24X,F8.1,2X,  
2'USG',//,20X,'VESSEL DIAMETER',22X,F8.1,2X,'FT',//,20X,'VESSEL HEI  
GHT',24X,F10.1,2X,'FT',//,20X,'MOTOR R.P.M.',23X,F10.1,//,20X,'MOTOR  
4R HORSE POWER',20X,F8.1,/) )
```

```
WRITE(6,201)XMIX(8),XMIX(20),XMIX(15),XMIX(14),XMIX(6),XMIX(16)
```

```
201 FORMAT(20X,'IMPELLER TYPE',22X,'TURBINE WITH',/,50X,'45 DEG. PITCH  
AND BLADES',//,20X,'NUMBER OF BLADES',24X,F4.0,//,20X,'TURNING DIRECTION',  
21X,F8.1,2X,'INS.',//,20X,'BLADE WIDTH',26X,F8.1,2X,'INS.',//  
3//,20X,'DISTANCE OF IMPELLER FROM',/,20X,'BOTTOM OF VESSEL',21X,F8.  
41,2X,'INS.',//,20X,'NUMBER OF BAFFLES',23X,F4.0,//,20X,'BAFFLE HIG  
5TH',25X,F8.1,2X,'INS.',///)
```

```
WRITE(6,202)NN
```

```
202 FORMAT(20X,'TABLE',13,5X,'SULPHUR RECOVERY UNIT',/,33X,'AGITATOR S
```



```
1X,F6.1,/) )
```

```
WRITE(6,104)NN
```

```
104 FORMAT(20X,'TABLE',13,5X,'SULPHUR RECOVERY UNIT',7,33X,'PROCESS V  
13SFL SIZES')
```

```
WRITE(6,10)
```

```
NN=NN+1
```

```
WRITE(6,95)
```

```
95 FORMAT(// ,20X,'HEAT EXCHANGER',//,16X,'FLUIDSHEET NUMBER',12X,  
1E-2',//,16X,'SERVICE',24X,'RICH SOLVENT COOLER')
```

```
WRITE(6,90)HDUTY(2),(HE(I),I=14,21)
```

```
90 FORMAT(/// ,16X,'TOTAL HEAT DUTY',14X,F12.1,2X,'BTU/HR',//,16X,'NU  
MBER OF UNITS',21X,F4.0,2X,'PLACED IN SHEETS',//,16X,'HEAT DUTY PE  
2R UNIT',11X,F12.1,2X,'BTU/HR',//,16X,'LOG MEAN TEMPERATURE DIFFERE  
3NCE',3X,F7.1,2X,'DEG.F.',//,16X,'AREA PER UNIT',20X,F8.1,2X,'SQ.FT  
4.',//,16X,'OVERALL HEAT TRANSFER',7,16X,'COEFFICIENT --- CLEAN',13  
5X,F7.1,2X,'BTU/(HR)(SQ.FT)(DEG.F)',//,27X,' --- DIRTY',13X,F7.1,2X  
6,'BTU/(HR)(SQ.FT)(DEG.F)',//,16X,'DIRT FACTOR --- REQUIRED',13X,F7  
7.4,2X,'(HR)(SQ.FT)(DEG.F)/BTU',//,27X,' --- CALCULATED',11X,F7.4,7  
8X,'(HR)(SQ.FT)(DEG.F)/BTU',/)
```

```
WRITE(6,96)
```

```
96 FORMAT(/ ,45X,'SHELL SIDE',1X,'TUBE SIDE',///,16X,'FLUID IN  
1NDLED',14X,'SOLVENT RECYCLE',2X,'RICH SOLVENT',/)
```

```
WRITE(6,97)TOTAL(2),TOTAL(7),TEMP2(1),TEMP7(1),TEMP2(2),TEMP7(2),V  
1IS(30),VIS(28),VIS(31),VIS(29),DENS(30),DENS(23),DENS(31),DENS(25)
```



```

97 FORMAT(16X,'FLOW RATE',7X,'LBS/HR',7X,F12.1,3X,F12.1,/,16X,'TEMPERATURES',/,2X,'INLET',7X,'DEG.F.',12X,F7.1,8X,F7.1,/,2X,'OUTLET',2X,AX,'DEG.F.',12X,F7.1,8X,F7.1,/,16X,'VISCOSITY',/,2X,'INLET',7X,2,'CPS',15X,F7.2,8X,F7.2,/,2X,'OUTLET',AX,'CPS',15X,F7.2,8X,F7.2,4//,16X,'DENSITY',/,2X,'INLET',7X,'LBS/CU.FT.',7X,F9.2,7X,F9.2,/,52X,'OUTLET',AX,'LBS/CU.FT.',7X,F9.2,7X,F9.2,/)

```

```

WRITE(6,98)(HE(11),11=22,73)

```

```

98 FORMAT(16X,'CALCULATED',/,2X,'PRESSURE DROP',3X,'PSI',14X,F7.1,8X,1,F7.1,/)

```

```

WRITE(6,91)NN

```

```

91 FORMAT(20X,'TABLE',13,5X,'SULPHUR RECOVERY UNIT',/,13X,'HEAT EXCHANGER SPECIFICATIONS')

```

```

WRITE(6,10)

```

```

NN=NN+1

```

```

WRITE(6, 92)(HE(J),J=1,4),HE(24),HE(7)

```

```

92 FORMAT(////,16X,'TUBE LENGTH',18X,F5.1,2X,'FT.',/,16X,'TUBE INSIDE DIAMETER',11X,F5.3,2X,'INS.',/,16X,'TUBE OUTSIDE DIAMETER',10X,2F5.3,2X,'INS.',/,16X,'TUBE PITCH',2X,F7.4,2X,'INS.',/,16X,'TUBE IS PER UNIT',13X,F6.0,/,16X,'NUMBER OF TUBE PASSES',8X,F4.0,/)

```

```

WRITE(6,93)HE(11),HE(25)

```

```

93 FORMAT(16X,'SHELL INSIDE DIAMETER',7X,F7.2,2X,'INS.',/,16X,'SHELL IE SPACING',14X,F6.1,2X,'INS.',////)

```

```

WRITE(6,91)NN

```

```

WRITE(6,10)

```


NN=NN+1

WRITE(6,110)TOTAL(16),TOTAL(15),TOTAL(17),Q(11),Q(13),Q(7)

111 FORMAT(////,16X,'TOTAL SLURRY FEED TO FILTER UNITS',5X,F10.1,2X,'LBS/HR',/,16X,'TOTAL WASH TO FILTER UNITS',12X,F10.1,2X,'LBS/HR',/,2/,16X,'TOTAL SOLID PRODUCT FX FILTER UNITS',3X,F10.1,2X,'LBS/HR',/,3/,16X,'NUMBER OF FILTER UNITS',20X,F5.0,/,16X,'FILTER DRUM AREA',423X,F9.1,2X,'SQ.FT/UNIT',/,16X,'DRUM ROTATION SPEED',23X,F7.2,2X,'R.P.M.',/,/)

WRITE(6,111)D(2),S(14),H(11)

111 FORMAT(16X,'PRESSURE DROP ACROSS FILTER',15X,F7.2,2X,'PSI',/,16X,'VACUUM PUMP CAPACITY',/,16X,'AT PUMP INLET CONDITIONS',15X,F9.1,2X,'GPM',/,16X,'VACUUM PUMP MOTOR SIZE',10X,F9.1,2X,'HHP',/,3////)

WRITE(6,112)NN

112 FORMAT(20X,'TABLE',13,5X,'SULPHUR RECOVERY UNIT',/,33X,'ROTARY VACUUM FILTER SPECIFICATIONS')

WRITE(6,10)

NN=NN+1

WRITE(6,50)HDUTY(1)

WRITE(6,51)F3

WRITE(6,52)STORE(1)

WRITE(6,53)CC

WRITE(6,54)STORE(2)

WRITE(6,55)SS


```

WRITE(6,56)NN
50 FORMAT(////,16X,'HEAT DUTY',31X,F12.1,2X,'BTU/HR',//)
51 FORMAT(16X,'HEATER THERMAL EFFICIENCY',21X,F6.1,//)
52 FORMAT(16X,'GAS REQUIREMENT',28X,F9.1,2X,'SCF/HR',//)
53 FORMAT(16X,'HEATING VALUE OF GAS',24X,F8.1,2X,'BTU/SCF',//)
54 FORMAT(16X,'AIR REQUIREMENT',25X,F11.1,2X,'SCF/HR',//)
55 FORMAT(16X,'PERCENTAGE STOICHIOMETRIC',/,16X,'AIR REQUIREMENT',31X
1,F6.1,////)
56 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,33X,'SOLVENT RE
1CYCLE HEATER')
WRITE(6,17)
NN=NN+1
WRITE(6,40)
40 FORMAT(////,17X,'PUMP DUTY',7X,'GPM',4X,'CAPACITY',1X,'MOTOR',/,1
17X,'NUMBER',7X,'USGPM',4X,'HORSE POWER',//)
WRITE(6,41)CAP(1),HP(1)
WRITE(6,42)CAP(2),HP(2)
WRITE(6,43)CAP(3),HP(3)
WRITE(6,44)CAP(4),HP(4)
WRITE(6,45)CAP(5),HP(5)
WRITE(6,46)CAP(6),HP(6)
WRITE(6,66)CAP(7),HP(7)
WRITE(6,67)CAP(8),HP(8)
41 FORMAT(18X,'SOLVENT',/,18X,'SLURRY',/,16X,'CIRCULATION',4X,'1',7X,

```



```

10 F3.1,7X,F7.1,/)
42 FORMAT(15X,'WATER/SOLVENT',/,18X,'SLURRY',/,16X,'CIRCULATION',8X,'
12',7X,F3.1,7X,F7.1,/)
43 FORMAT(19X,'SLUDGE',/,18X,'DISPOSAL',9X,'3',7X,F8.1,7X,F7.1,/)
44 FORMAT(15X,'COOLING WATER',/,18X,'DISPOSAL',9X,'4',7X,F3.1,7X,F7.1
1,/)
45 FORMAT(15X,'FILTRATE PUMP',7X,'5',7X,F8.1,7X,F7.1,/)
46 FORMAT(15X,'COOLING WATER',/,19X,'FEED',12X,'6',7X,F8.1,7X,F7.1,/)
66 FORMAT(18X,'SULPHUR',/,18X,'SLURRY',/,16X,'CIRCULATION',8X,'7',7X,
1F3.1,7X,F7.1,/)
67 FORMAT(16X,'LEAN SOLVENT',/,18X,'RECYCLE',10X,'8',7X,F3.1,7X,F7.1,
1//)
WRITE(6,47)NN
47 FORMAT(/////,20X,'TABLE',11,5X,'SOLUTION OVERFLOW UNIT',/,33X,'PUMP
1CAPACITY & MOTOR SIZES')
WRITE(6,10)
NN=NN+1
WRITE(6,60)
WRITE(6,61)(CON(1,J),J=1,5),HP(9),DENS(1)
WRITE(6,62)(CON(2,J),J=1,5),HP(10),DENS(17)
WRITE(6,63)NN
60 FORMAT(/////////,11X,'BELT DUTY',4X,'BELT',4X,'BELT',4X,'BELT',6X,
1'BELT',5X,'BELT',4X,'BELT',3X,'MOTOR',11,'MATERIAL',/,15X,'NUMBER')

```



```

2,3X,'RISE',3X,'LENGTH',3X,'CAPACITY',3X,'WIDTH',3X,'SPEED',3X,'HOR
3SE',4X,'DENSITY',/,75X,'POWER',/,33X,'FT',6X,'FT',5X,'S.TON/HR',4X
4,'FT/SEC',4X,'FT/FTK',4X,'LBS/CU.FT',/,//)

61 FORMAT(11X,'ORE FEED',/,11X,'TO PLANT',7X,'1',2X,F7.1,F9.1,2X,F9.1
1,2X,F6.1,2X,F5.2,1X,F7.1,3X,F6.1,//)

62 FORMAT(11X,'SULPHUR',/,11X,'PRODUCT',4X,'1',2X,F7.1,F9.1,2X,F9.1,2
1X,F6.1,2X,F6.0,1X,F7.1,3X,F6.1,///)

63 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,33X,'CONVEYOR S
1PECIFICATIONS')

WRITE(6,10)
NN=NN+1
WRITE(6,30)

30 FORMAT(///,13X,'STREAM',3X,'STREAM',3X,'PIPE DIAMETER',3X,'FLUID',
15X,'PRESSURE DROP',/,16X,'FLOWSHEET',2X,'SECTION',2X,'NOMINAL POR
2E',2X,'VELOCITY',3X,'PER 100FT LENGTH',/,18X,'NUMBER',15X,'INCHES.
3',6X,'FT/SEC',4X,'TOP LINE',/,64X,'LBS/SEC. IN.',///)

DO 31 I=2,11
IF(I.EQ.2) GO TO 32
IF(I.EQ.6) GO TO 31
IF(I.EQ.7) GO TO 33
WRITE(6,34)I,DIDPT(I),VEL(I),DP(I)

34 FORMAT(20X,I2,16X,F6.1,7X,F7.1,7X,F8.2,/)

GO TO 31

35 J=1,3

```


L=J+29

35 WRITE(6,36)I,J,DIOPT(L),VEL(L),DP(L)

36 FORMAT(20X,I2,2X,I1,7X,F6.1,7X,F1.1,7X,F10.1,7)

GO TO 31

33 DO 37 K=1,2

M=K+27

37 WRITE(6,36)I,K,DIOPT(M),VEL(M),DP(M)

31 CONTINUE

MM=24

DO 39 J=13,19

IF(J.EQ.14) GO TO 28

WRITE(6,34)J,DIOPT(MM),VEL(MM),DP(MM)

IF(J.EQ.14) GO TO 39

MM=MM-1

GO TO 39

28 WRITE(6,34)J,DIOPT(15),VEL(15),DP(15)

39 CONTINUE

JPP=26

DO 125 JP=22,23

WRITE(6,34)JP,DIOPT(JPP),VEL(JPP),DP(JPP)

125 JPP=JPP+1

WRITE(6,38)NN

38 FORMAT(20X,'TABLE ',I3,5X,'SULPHUR RECOVERY UNIT',7,30X,'LINE SIZES'
1 & PRESSURE DROPS')


```

WRITE(6,10)
NM=NM+1
WRITE(6,500)
500 FORMAT(////,20X,'EQUIPMENT ITEM',5X,'UNIT COST',8X,'TOTAL COST',/,
140X,'U.S. $',12X,'U.S. $',/)
DO 501 IO=1,2
501 WRITE(6,502)IO,(UNITCT(IO,IO),IO=1,2)
502 FORMAT(24X,'D - ',12,8X,F9.0,9X,F9.0,/)
DO 503 IDI=1,2
IDIO=IDI+2
503 WRITE(6,504)IDI,(UNITCT(IDIO,IDIO),IDIO=1,2)
504 FORMAT(24X,'S - ',12,8X,F9.0,9X,F9.0,/)
WRITE(6,505)(UNITCT(5,IO),IO=1,2)
505 FORMAT(24X,'A - ',12,8X,F9.0,9X,F9.0,/)
DO 506 IOO=1,2
IOOD=8-IOO
506 WRITE(6,507)IOO,(UNITCT(IOOD,IO),IO=1,2)
507 FORMAT(24X,'E - ',12,8X,F9.0,9X,F9.0,/)
WRITE(6,508)(UNITCT(8,IO),IO=1,2)
508 FORMAT(24X,'F - ',12,8X,F9.0,9X,F9.0,/)
IPN=1
DO 509 IPNO=9,17
WRITE(6,510)IPN,(UNITCT(IPNO,IO),IO=1,2)
509 IPN=IPN+1

```



```

510 FORMAT(24X,'P - ',I2,8X,F9.0,9X,F9.0,/)
      DO 511 ICON=1,2
      ICON=ICON+17
511 WRITE(6,512)ICON,(UNITCT(ICON,IO),IO=1,2)
512 FORMAT(24X,'C - ',I2,2X,F9.0,7X,F9.0,/)
      WRITE(6,513)UNITCT(39,2)
513 FORMAT(/,54X,'-----',/,20X,'SUB TOTAL',27X,F9.0,/,54X,'--
1-----',/)
      WRITE(6,514)NN
514 FORMAT(20X,'TABLE',I3,5X,'SULPHUR RECOVERY UNIT',/,33X,'ESTIMATED
1EQUIPMENT COSTS')
      WRITE(6,10)
      WRITE(6,500)
      WRITE(6,515)UNITCT(39,2)
515 FORMAT(20X,'SUB TOTAL',27X,F9.0,/)
      LIPO=1
      DO 516 IPO=1,27
      IPO=IPO+1
516 LIPO=LIPO+1
517 FORMAT(20X,'MOTOR FOR P - ',I2,2X,F9.0,9X,F9.0,/)
      WRITE(6,517)LIPO,(UNITCT(30,IO),IO=1,2)
      DO 518 IPCO=1,2
      IPCO=IPCO+27
518 WRITE(6,519)IPCO,(UNITCT(IPCO,IO),IO=1,2)

```



```
519 FORMAT(20X,'MOTOR FOR C - ',I2,2X,F9.0,9X,F9.0,/)

```

```
WRITE(6,521)(UNITCT(31,IO),IO=1,7)

```

```
521 FORMAT(20X,'MOTOR FOR A - 1',2X,F9.0,9X,F9.0,/)

```

```
DO 522 ITT=1,2

```

```
ITTO=ITT+1

```

```
522 WRITE(6,523)ITT,(UNITCT(ITTO,IO),IO=1,2)

```

```
523 FORMAT(20X,'MOTOR FOR S - ',I2,2X,F9.0,9X,F9.0,/)

```

```
WRITE(6,524)UNITCT(40,2)

```

```
524 FORMAT(//,54X,'-----',/,20X,'TOTAL',32X,F9.0,/,54X,'-----'

```

```
1-----',//)

```

```
WRITE(6,514)NN

```

```
WRITE(6,10)

```

```
NN=NN+1

```

```
WRITE(6,800)

```

```
800 FORMAT(////,26X,'FRACTION OF',5X,'COST',7X,'INITIAL CAPITAL',/,17X,'
(PURCHASED)',21X,'INVESTED',/,57X,'EQUIPMENT',/,89X,'COSTS',/,99X,'
2',14X,'$',//)

```

```
WRITE(6,801)(FRACT(IC),CAPIT(IC),IC=1,9)

```

```
801 FORMAT(18X,'DIRECT COSTS',/,18X,'PURCHASED EQUIP',4X,F6.0,7X,F9.
10,/,18X,'PURCHASED EQUIP',/,18X,'INSTALLATION',4X,F6.0,7X,F9.0,/,
2,18X,'INSTRUMENTATION',5X,F6.0,4X,F10.0,/,18X,'PIPING',14X,F6.0,4X
2,F10.0,/,18X,'ELECTRICS',11X,F6.0,6X,F10.0,/,18X,'BUILDINGS',/,18X
4,'(INC. SERVICES)',4X,F6.0,6X,F10.0,/,18X,'YARD IMPROVEMENTS',3X,F
56.0,6X,F10.0,/,18X,'SERVICES',12X,F6.0,5X,F10.0,/,18X,'LAND PURCHAS

```



```

      75F4,7X,F6.0,6X,F10.0,/)
      WRITE(6,802)HP(20)
802 FORMAT(16X,'TOTAL DIRECT PLANT COST',26X,F10.0,/)
      WRITE(6,803)(FRACT(ICC),CAPIT(ICC),ICC=10,11)
803 FORMAT(16X,'INDIRECT COSTS',/,18X,'ENGINEERING &',/,13X,'SUPERVIS
      ION',9X,F6.0,/,9X,F10.0,/,18X,'CONSTRUCTION',/,20X,'EXPENSE',11X,F6.
      0,6X,F10.0,/)
      WRITE(6,804)CAPIT(10)
804 FORMAT(16X,'TOTAL DIRECT AND',/,18X,'INDIRECT PLANT COSTS',26X,F1
      0.0,/)
      WRITE(6,805)(FRACT(IQ),CAPIT(IQ),IQ=12,13)
805 FORMAT(18X,'CONTRACTORS FEES',4X,F6.0,10X,F10.0,/,18X,'CONTINGENCY'
      1,9X,F6.0,6X,F10.0,/)
      WRITE(6,806)CAPIT(16)
806 FORMAT(16X,'FIXED CAPITAL INVESTMENT',26X,F10.0,/)
      WRITE(6,808)FRACT(14),CAPIT(14)
808 FORMAT(18X,'WORKING CAPITAL',5X,F6.0,6X,F10.0,/)
      WRITE(6,809)CAPIT(17)
809 FORMAT(64X,'-----',/,16X,'TOTAL CAPITAL INVESTMENT',25X,F10
      0.0,/,64X,'-----',///)
      WRITE(6,807)NN
807 FORMAT(20X,'TABLE',13,5X,'SULPHUR RECOVERY UNIT',/,33X,'PLANT FIXE
      D CAPITAL INVESTMENT BASED ON',/,33X,'DELIVERED EQUIPMENT COSTS')
      WRITE(6,10)

```


NN=NN+1

WRITE(6,900)

900 FORMAT(//,24X,'COST ITEM',15X,'\$',21X,'\$',//)

WRITE(6,901)(COSTMAN(NC),NC=1,10)

901 FORMAT(19X,'RAW MATERIALS',6X,F15.0,/,19X,'ELECTRICITY',8X,F15.0,
1/,19X,'COOLING WATER',6X,F15.0,/,19X,'NATURAL GAS',8X,F15.0,/,1
29X,'SOLVENT MAKE-UP',4X,F15.0,/,19X,'OPERATING LABOUR',3X,F15.0,/
3/,19X,'SUPERVISION',7X,F15.0,/,19X,'MAINTENANCE',8X,F15.0,/,19X,
4'OPERATING SUPPLIES',1X,F15.0,/,19X,'LABORATORY CHARGES',1X,F15.
5,//)

WRITE(6,902)COSMST(1)

902 FORMAT(19X,'DIRECT PRODUCTION',/,19X,'COSTS',8X,F15.0,//)

WRITE(6,903)COSMST(5)

903 FORMAT(19X,'FIXED CHARGES',28X,F15.0,//)

WRITE(6,904)COSMST(2)

904 FORMAT(19X,'PLANT OVERHEADS',26X,F15.0,//)

WRITE(6,905)COSMST(3),COSMST(6),COSMST(7),COSMST(4)

905 FORMAT(19X,'ADMINISTRATION COSTS',F15.0,/,19X,'DISTRIBUTION COSTS
1',1X,F15.0,/,19X,'R & D CHARGES',6X,F15.0,/,19X,'INTEREST CHARGE
25',3X,F15.0,//)

WRITE(6,906)COSMST(1)

906 FORMAT(19X,'GENERAL EXPENSES',25X,F15.0,//)

WRITE(6,907)COSMST(8)

907 FORMAT(19X,'TOTAL PROJECT COST',24X,F15.0,///)


```
WRITE(6,908)COSMST(9)
```

```
908 FORMAT(19X,'PRODUCTION COST PER TON SULPHUR PRODUCT',F19.2,//)
```

```
WRITE(6,910)HP(19)
```

```
910 FORMAT(19X,'MANUFACTURING COST PER TON SULPHUR PRODUCT',F16.2,//)
```

```
WRITE(6,909)NN
```

```
909 FORMAT(20X,'TABLE',13,5X,'SULPHUR RECOVERY UNIT',/,3X,'10111' 10111
```

```
1UCTION COSTS')
```

```
WRITE(6,100)
```

```
NN=NN+1
```

```
WRITE(6,1001)(PDWR(IIU),IIU=2,5)
```

```
1001 FORMAT(////,17X,'ELECTRICITY',8X,F10.1,2X,'KWHR',//,17X,'COOLING W
```

```
LATER',5X,F10.1,2X,'M USG/HR',//,17X,'NATURAL GAS',5X,F10.1,2X,'M S
```

```
2CF/HR',//,17X,'SOLVENT MAKE-UP',4X,F10.1,2X,'USG/HR',///)
```

```
WRITE(6,1002)NN
```

```
1002 FORMAT(20X,'TABLE',13,5X,'SULPHUR RECOVERY UNIT',/,3X,'10111' 10111
```

```
1ITY REQUIREMENTS')
```

```
WRITE(6,100)
```

```
NN=NN+1
```

```
RETURN
```

```
END
```


SUBROUTINE PHASEV (MT,A4,T7)

C
C CALCULATES VISCOSITY FOR GIVEN TEMPERATURE
C

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),D10(40),VE1(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHFAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLQ(25),SOLUL(25),SOLP2(25),VISCOS(25,2),CRYT(25),TEMP7(2)

4 DO 6 LQ=1,25

IF(CRYT(LQ)-T7)6,7,8

7 A4=VISCOS(LQ,MT)

GO TO 5

8 CALL XINTER(T7,VISCOS(LQ,MT),VISCOS(LQ-1,MT),CRYT(LQ),CRYT(LQ-1),A
1AA)

A4=AAA

GO TO 5

6 CONTINUE

5 RETURN

END

SUBROUTINE PIPE(LUSGS,EROGS)

SIZES ALL PROCESS PIPES

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON MDOTY(2),CUM(13),VIS(40),SF(40),DP(140),TII(40),V(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLD(25),SGSOL(25),SGH2O(25),VISGUS(5,1),CXYT(25),TEMP(2)

DIAMETER CALCULATION

DO 1 II=3,32

JI=II

IF(II.EQ.7) GO TO 1

IF(II.EQ.12) GO TO 1

IF(II.EQ.17) GO TO 1

IF(II.GE.28) JI=7

IF(II.GE.30) JI=2

CALL DIAM(JI,II,OI)

DO 7 K247=1,12

IF(D(K247)-OI)7,8,8

7 CONTINUE

VELOCITY CALCULATION

8 VEL(II)=(576.*TOTAL(JI))/(DENS(II)*3600.*(D(K247)**2)*3.1416)

IF(II.EQ. 3) CALL VSET(K247,II,EROGS,LUSGS)

IF(II.EQ. 5) CALL VSET(K247,II,EROGS,LUSGS)

IF(II.EQ. 9) CALL VSET(K247,II,EROGS,LUSGS)

IF(II.EQ.10) CALL VSET(K247,II,EROGS,LUSGS)

STORES PIPE SIZE

DID(II)=D(K247)

DIDPT(II)=DWT(K247)

1 CONTINUE

RETURN

NO

SUBROUTINE PMUD(I,J,AV,R)

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON PDUTY(2),DUMP(40),VIS(40),OP(40),OP1(40),O1OP(40),VEL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

CALL CPVAL(I,J,AV)

CALL QBTU(I,R)

DUMP(I)=R

RETURN

END


```
SUBROUTINE PPTF(I,K,QQ,RR,T,SCRY)
```

```
ESTIMATES HEAT REMOVED IN CRYSTALLISING SULPHUR
```

```
IN DT RANGE OF 0.1 DEG.F.
```

```
COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TIME2(1)
```

```
COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DIO(40),VEL(40)
```

```
COMMON REX(50,8),U(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)
```

```
COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)
```

```
COMMON SOLD(25),SGSOL(25),SGH2O(25),VISCOS(25,2),CRYT(25),TEMP7(2)
```

```
IF(T)1,1,2
```

```
1 DT=TEMP(I)
```

```
CALL SOLUB(TEMP(I),SD,1)
```

```
2 T=DT-.1
```

```
112 A=SD
```

```
CALL SOLUB(T,SD,1)
```

```
SPPTF=((A/(1.-A))-(SD/(1.-SD)))*SOL(T)
```

```
TAV=(DT+T)/2.
```

```
CALL CPVAL(7,3,TAV)
```

```
CALL HEATOC(TAV,HCRYT)
```

```
Q=((SOL(I)+S(1)-SCRY)*CP(2)+SCRY*CP(5)+U(I)*CP(2)+H2O(I)*CP(3))*  
1DT-T)+(HCRYT*SPPTF)
```

```
SCRY=SCRY+SPPTF
```

```
QQ=QQ+Q
```

```
14 DT=T
```



```
IF(PP)1,4,1
```

```
4 IF(T-TEMP(K))3,3,2
```

```
3 RETURN
```

```
END
```


SUBROUTINE PRICE(AQ,BQ,CQ,DQ)

DQ=AQ*BQ*CQ

RETURN

END


```
SUBROUTINE PUMP(I,J,K,Z,PUMPEF,XMOTEF,EXDP,P1,P2)
```

```
C PUMP CALCULATION
```

```
C COMMON DI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)
```

```
C COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DIP(40),VEL(40)
```

```
C COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)
```

```
C COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)
```

```
C HQ=Z+DIP1(K)+((P2-P1)*144./DENS(K))+EXDP
```

```
C HP(I)=(WQ*TOTAL(J))/(3600.*550.*PUMPEF*XMOTEF)
```

```
C CAP(I)=(TOTAL(J)*7.48)/(DENS(K)*60.)
```

```
C RETURN
```

```
C END
```


SUBROUTINE QBTU(I,W)

DETERMINES M CP VALUES FOR A SPECIFIED STREAM

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),PP(40),DIO(40),VEL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

IF(M)1,2,3

1 BB=OI(I)*CP(1)+(SOL(I)+S(I))*CP(2)+H2O(I)*CP(3)

GO TO 4

2 B=SOL(I)*CP(4)

BB=B

GO TO 4

3 B=OI(I)*CP(1)+S(I)*CP(5)+H2O(I)*CP(3)+SOL(I)*CP(4)

BB=B

4 W=BB

7 RETURN

END

SUBROUTINE QBTU2(R,IS,P)

C
C DETERMINES H₂O, H₂O₂ VALUES FOR A SPECIFIED STREAM
C

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

P=R*(TEMP(IS)-32.0)

RETURN

END

SUBROUTINE QBTU4(QR,IP,RR)

C ESTIMATES TEMPERATURE OF A STREAM AFTER HEATING

C OR COOLING

C COMMON Q1(30),S(20),SOL(30),H2O(10),TOTAL(20),TEMP(30),TEMP2(3)

TEMP2(IP)=(QR/24)+TEMP2(IP-1)

RETURN

END

SUBROUTINE RATIO(R,ET,CF)

DETERMINES WATER REQUIRED TO WASH ORE SOLVENT SLURRY

FREE OF SOLVENT

COMMON OI(3),S(40),SOL(3),H2O(10),TOTAL(30),TEMP1(3),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DIO(40),VEL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOP(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLD(25),SGSOL(25),SCH2O(25),VISCUS(25,2),CRYT(25),TEMP7(2)

CALL SOLUB(ET,BB,3)

CALL SOLUB(ET,CC,4)

H2O(4)=(SOL(3)*R*CC)/BB

H2O(5)=H2O(3)+H2O(4)

H2O(6)=H2O(5)

H2O(20)=H2O(6)-((OI(6)*(1.-CF))/CF)

RETURN

END

SUBROUTINE REN(P,Q,R,S)

C
C REYNOLDS NUMBER CALCULATION
C

S=(P*R)/Q

RETURN

END


```
SUBROUTINE RHO(SGSUL,SGORE)
```

```
CALCULATES STREAM DENSITIES
```

```
COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)
```

```
COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),HP(130),DIO(40),VFI(40)
```

```
COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)
```

```
COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)
```

```
COMMON SOLD(25),SGSOL(25),SGH2O(25),VISCOS(25,2),C,VT(25),TEMP2(3)
```

```
DO 1 I=1,27
```

```
IF(I.EQ.2) GO TO 2
```

```
IF(I.EQ.7) GO TO 3
```

```
T=TEMP(I)
```

```
CALL SOLUB(T,C,3)
```

```
CALL SOLUB(T,R,4)
```

```
IF(I.EQ.1) GO TO 4
```

```
IF(I.EQ.17)GO TO 4
```

```
IF(I.EQ.3) GO TO 4
```

```
IF(I.EQ.9) GO TO 4
```

```
IF(I.EQ.10)GO TO 4
```

```
IF(I.EQ.25) GO TO 4
```

```
E=S(I)/C
```

```
GO TO 5
```

```
4 E=S(I)/SGSOL
```

```
5 DENS(I)=(TOTAL(I)*62.4)/((SOL(I)/C)+H2O(I)/R+(OI(I)/SGORE)+E)
```



```
GO TO 1
2 DO 6 J=1,3
  T=TEMP2(J)
  CALL SOLUB(T,A,3)
  DENS(J+29)=A*62.4
6 CONTINUE
GO TO 1
3 DO 7 K=1,2
  T=TEMP1(K)
  CALL SOLUB(T,B,3)
  DENS(K+27)=B*62.4
7 CONTINUE
1 CONTINUE
RETURN
END
```


SUBROUTINE SEIGHT(R,A,I)

ESTIMATES WATER REQUIRED TO WASH SOLVENT SULPHUR SLURRY

FREE OF SOLVENT

COMMON RI(20),S(30),SOL(30),H2O(10),TOTAL(10),TEMP(30),TEMP1(4)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DIO(40),VEL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),H2(10),SLOPE(10),PBT(5,2)

COMMON SOLD(25),SGSOL(25),SGH2O(25),VISCOS(25,2),CRYT(25),TEMP7(2)

IF(I.EQ.15) GO TO 1

CALL SOLUB(TEMP(10),BB,3)

CALL SOLUB(TEMP(10),CC,4)

R=(R*CC)/BB

1 H2O(I)=R*A

TOTAL(I)=H2O(I)

RETURN

END


```
SUBROUTINE SET2(I4,J4,K4,L4,I9,I8,I10,SGSUL,I7,FL,FEL,IMN)
```

```
SETTLER DESIGN AFTER CHL & CLEVENSON (25)
```

```
DIMENSION SURF(4)
```

```
COMMON DI(3),S(3),SOL(30),H2O(50),TOTAL(2),TEMP(30),TEMP2(3)
```

```
COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DPI(40),DID(50),VEL(4)
```

```
COMMON PEX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)
```

```
COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STRESS(30),RELT(2,2)
```

```
COMMON SOLD(25),SGSOL(25),SGH2O(25),VISCOS(25,2),CRYT(25),TEMP7(2)
```

```
COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3),SETDIA(10,2)
```

```
UPPER PORTION OF VESSEL
```

```
SETTLING VELOCITY OF A SOLID PARTICLE IN SOLVENT PHASE
```

```
PHASE DENSITIES
```

```
CALL SOLUB(TEMP(I4),X1,3)
```

```
CALL SOLUB(TEMP(I4),Y1,4)
```

```
PHASE VISCOSITY
```

```
CALL PHASEV(1,A1,TEMP(I4))
```

```
CALL STOKES(X1,SGSUL,A1,DUMP(30),VSP)
```

```
RISEING VELOCITY OF A SOLVENT PARTICLE IN WATER PHASE
```



```
CALL PHASEV(2,B1,TEMP(I4))
```

```
CALL STOKES(Y1,X1,B1,DUMP(29),VS)
```

```
SETTLING VELOCITY OF A WATER PARTICLE IN SOLVENT PHASE
```

```
CALL STOKES(Y1,X1,A1,DUMP(29),VW)
```

```
VESSEL DIAMETER
```

```
IF(VSP>.3T,VW)VSP=VW
```

```
K5=K4
```

```
IF(K4<.7).71K5=.25
```

```
CALL ARA(VSP,K4,SURF(1),K5)
```

```
CALL ARA(VS,J4,SURF(2),J4)
```

```
LEADER POSITION AREA ESTIMATION
```

```
SURF(3)=((FL-FLL)*TOTAL(J4)*DUMP(28))/(62.4*Y1*DUMP(I7)*3600.)
```

```
CALL STOKES(Y1,SGSUL,B1,DUMP(30),VSS)
```

```
CALL APA(VSS,I8,SURF(4),I8)
```

```
VESSEL AREA DETERMINATION
```



```
XX=SURF(1)
```

```
DO 1 JA=2,4
```

```
IF (SURF(JA).NE.1.XX) XX=SURF(JA)
```

```
1 CONTINUE
```

```
VESSEL HEIGHT CALCULATION
```

```
CALL ARA(XX,K4,V1,K5)
```

```
VOL(L4,3)=V1*DUMP(27)
```

```
VOL(L4,3)=VOL(L4,3)+3.0
```

```
VOL(L4+1,3)=(((SGSUL-Y1)*DUMP(I10)*DUMP(28)*TOTAL(J4)))/(3600.*XX*SG  
1SUL*62.4*((DENS(I9)/62.4)-Y1))
```

```
VOL(L4+1,3)=VOL(L4+1,3)+3.0
```

```
VESSEL DIAMETER & VOLUME
```

```
VOL(L4,2)=SQRT((4.*XX)/3.1416)
```

```
VOL(L4+1,2)=VOL(L4,2)
```

```
CALL VOLCAL(VOL(L4,3),XX,VOL(L4,1))
```

```
CALL VOLCAL(VOL(L4+1,3),XX,VOL(L4+1,1))
```

```
DO 2 ILOOK=1,10
```

```
IF(SETDIA(ILOOK,1)-VOL(L4,2))2,3,3
```

```
2 CONTINUE
```

```
3 HP(IMN)=SETDIA(ILOOK,2)
```


RETURN

END

SUBROUTINE SEVEN(I,J,K)

EVALUATES STREAM COMPONENTS AT BRANCHING

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

S(I)=S(J)-S(K)

SOL(I) =SOL(J)-SOL(K)

OI(I)=OI(J)-OI(K)

CALL SUB(I,J,K)

CALL SUB(I)

RETURN

END

SUBROUTINE SOLUB(CT,SD,N)

ESTIMATES SOLUBILITY, DENSITY OR VISCOSITY OF STREAM FOR
A GIVEN TEMPERATURE

DIMENSION A(25),B(25)

COMMON DI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DPI(40),DIO(40),VEL(40)

COMMON WEX(5,1),W(25),DI(10),DNI(12),PMFT(13),SF-EAT(13,2),CR(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLD(25),SGSOL(25),SGH2O(25),VISCUS(25,2),CRYT(25),TEMP7(2)

IF(N.EQ.1)GO TO 1

IF(N.EQ.2)GO TO 2

IF(N.EQ.3)GO TO 40

IF(N.EQ.4)GO TO 50

1 DO 12 I=1,25

A(I)=CRYT(I)

12 B(I)=SOL(I)

C=CT

3 GO TO 20

40 DO 41 I=1,25

A(I)=CRYT(I)

41 B(I)=SGSOL(I)

C=CT

GO TO 20

50 DO 51 I=1,25

A(I)=C*YI(I)

51 B(I)=SGH2D(I)

C=CT

GO TO 20

2 DO 11 I=1,25

A(I)=SOLD(I)

11 B(I)=C*YI(I)

C=SD

20 DO 23 I=1,25

IF (A(I)-C)G3,22,21

21 CALLXINTER(C,B(I),N(I-1),A(I),A(I-1),E)

GO TO 32

22 C=B(I)

GO TO 30

23 CONTINUE

30 IF(N.EQ.2)GO TO 31

SD=E

GO TO 32

11 CT=F

32 RETURN

END

SUBROUTINE STOKES(X,Y,A,C,VS)

C STOKES VELOCITY CALCULATION

VS=(32.17*62.4*ABS(X-Y)*C*C)/(18.*.000672*((304.8)**2)*A)

RETURN

END

SUBROUTINE SUB(I,J,K)

C

C

EVALUATES STREAM COMPONENTS AT BRANCHING

C

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

H2O(I)=H2O(J)-12*(K)

RETURN

END

SUBROUTINE SUM(I)

C

C SUMS STREAM COMPONENTS

C

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

TOTAL(I)=OI(I)+H2O(I)+S(I)+SOL(I)

RETURN

END


```
SUBROUTINE TANK(I4,J4)
```

```
SOLVENT STORAGE TANK SIZING
```

```

COMMON DI(10),S(24),SOL(70),H2O(10),TOTAL(10),TEMP(10),TEMP2(10)
COMMON H2OXY(2),TUMP(30),VIS(40),DP(40),DPI(40),DII(40),VEL(40)
COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)
COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)
COMMON SOLQ(25),SOSOL(25),SODPI(25),VISOLS(25,2),CEY1(25),REF=7(2)
COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3)

VR=(Q(1)*24.*TOTAL(I4)*7.48)/DENS(I4)

VHE=(Q(3)*HE(1)*(HE(11)*2)*3.1416*7.48)/57.3.

VHM=VOL(6,1)*Q(4)

VOL(J4,1)=(VHM+VR+VHE)*(Q(2)+1.0000)

VOL(J4,2)=(((VOL(J4,1)*4.)/(3.1416*7.48))**.75.1)

VOL(J4,3)=VOL(J4,2)

RETURN

END
```



```
SUBROUTINE TANK2(L,M,KL,NI,NP,NO,K)
```

```
DISCHARGE RATE: SOLVENT SEPARATOR SIZING
```

```
COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)
```

```
COMMON HDUTY(2),DUMP(30),VIS(40),DB(40),DPI(40),HID(40),VEL(40)
```

```
COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)
```

```
COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)
```

```
COMMON SOLD(20),SOL(20),GH2O(20),VL(20),VH(20),TEMP(20)
```

```
COMMON COM(2,7),HE(20),XPT(17,2),VIBN(2,2),VOL(11,3)
```

```
STOKES VELOCITY
```

```
CALL PHASEV(L,U,TEMP(NI))
```

```
CALL SOLUB(TEMP(NI),X,3)
```

```
CALL SOLUB(TEMP(NI),Y,4)
```

```
CALL STOKES(X,Y,U,DUMP(K),VR)
```

```
VESSEL DIAMETER, HEIGHT & CAPACITY
```

```
CALL ARA(VR,KL,AERA,KL)
```

```
VOL(M,2)=SQRT((4.*AERA)/3.1416)
```

```
CALL ARA(AERA,KL,VDW,KL)
```

```
VOL(M,3)=DUMP(NP)*VDW
```

```
CALL VOLCAL(VOL(M,3),AERA,VOL(M,1))
```


RETURN

END

SUBROUTINE TFIND(A,C,D,I)

ESTIMATES TEMPERATURE OF TWO MIXED STREAMS

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

TEMP(I)=((C-A)/D)+32.0

RETURN

END

SUBROUTINE TMIX(I,J,K,A,B,C)

DETERMINES THE OUTLET TEMPERATURE OF TWO MIXED STREAMS

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),QPI(40),CIP(40),MSU(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMFT(13),SPHEAT(13,2),CP(5)

AV=32.

IT=1

IJ=2

3 CALL CPVAL(I,1,AV)

CALL QBTU(I,A)

CALL CPVAL(J,1,AV)

CALL QBTU(J,B)

IF(IT.GT.1)IJ=1

AV=(TEMP(I)+TEMP(J))/2.

CALL CPVAL(K,IJ,AV)

CALL QBTU(K,C)

CALL QBTU2(A,I,Z)

CALL QBTU2(B,J,Y)

IT(I.EQ.4) GO TO 2

ZZ=-7

GO TO 2

1 ZZ=7

2 CALL TFIND(ZZ,Y,C,K)

IT=IT+1

IF(IT.EQ.4) GO TO 4

GO TO 2

4 RETURN

END

SUBROUTINE TWOONE(II,JI)

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

S(II)=S(JI)

SOL(II)=SOL(JI)

CALL SUM(II)

RETURN

END

SUBROUTINE UCLEAN(AA,BB,CC)

C

C

OVERALL H/T COEFF. CALCULATION FROM FILM COEFFS.

C

$CC=ABS((AA*BB)/(AA+BB))$

3 RETURN

END

SUBROUTINE UTIL

PLANT UTILITY & LABOUR COST ESTIMATES

```
COMMON DI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)
```

```
COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),TID(40),VOL(40)
```

```
COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)
```

```
COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)
```

```
COMMON SOLD(25),SGSOL(25),SGH2O(25),VISCOS(25,2),CPYT(25),TEMP7(2)
```

```
COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3),SETDIA(10,2)
```

```
COMMON EQUIP(3,12,2),UNITCT(40,2),XMIX(20)
```

```
COMMON POWR(4),FPACT(14),CAP11(17),CPI(14),CPSMA(14),CPSMA1(14)
```

```
ORE FEED RATE
```

```
POWR(1)=TOTAL(1)/2000.
```

```
KWHR REQUIRED
```

```
A=40(1)
```

```
DO 1 IA=2,1
```

```
1 A=A+HP(IA)
```

```
DO 2 IB=11,14
```

```
2 A=A+HP(IB)
```

```
A=A+(HP(11)*Q(11))+(HP(12)*XMIX(2))
```


POWR(2)=A*1.1*.7457

WATER REQUIRED

POWR(3)=(TOTAL(24)*7.48)/(DENS(24)*1000.)

NATURAL GAS

POWR(4)=STORE(11)/1000.

SOLVENT MAKE-UP

POWR(5)=(TOTAL(12)*7.48)/(DENS(12))

OPERATORS PER SHIFT

POWR(6)=CPT(18)

RETURN

END

SUBROUTINE VACF(IFO,ISO,IDC,L3L,DR,PU)

VACUUM FILTER DESIGN SEE APPENDIX VII

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(30)

COMMON HDUTY(2),JUMP(20),VIS(40),DPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

W=(TOTAL(ISO)*DENS(IFO))/TOTAL(IFO)

Q(13)=(TOTAL(ISO)*Q(9)*VIS(IFO)*2.42)/(Q(5)*Q(8)*144.*W*Q(11))

VOA=(TOTAL(IDC)*Q(6)*VIS(IFO)*Q(9))/(Q(5)*Q(10)*Q(12)*W)

Q(14)=(14.67-14.67)/(14.67-14.67)

P=((3.03*1.4*144.*(14.67-Q(8))*Q(14))/((10.**5)*.4))*(((14.67)/(14.67-Q(8)))**(.4/1.4))-1.0000)

HP(L3L)=P/(DR*PU)

RETURN

END

SUBROUTINE VISAVG(ZZ,YY,XX,WW)

C

C

AVERAGE VISCOSITY CALCULATION

C

$YY = (ZZ + YY) / (2 + WW)$

RETURN

END

SUBROUTINE VOLCAL(X,Y,Z)

C
C VESSEL VOLUME CALCULATION IN U. S. GALLS.
C

$Z = Y * X * 7.48$

RETURN

END

SUBROUTINE VSET(K,I,SGORE,SGSUL)

C

C

MINIMUM PIPE VELOCITY TO PREVENT SOLIDS FROM

C

SETTLING DETERMINATION SPELLS(74) CORRELATION

C

COMMON PI(75),S(25),SOL(25),H2(15),TOTAL(15),TEMP(15),TEMP1(15)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DIO(40),VEL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(4),DIOPI(40),CAP(15),PR(20),STRET(20),BELT(5,20)

COMMON SOLD(25),SGSOL(25),SGH2O(25),VISCOS(25,2),CRYT(25),TEMP7(2)

CALL SOLUB(TEMP(I),A,3)

CALL SOLUB(TEMP(I),B,4)

C=0.00

IF(I.EQ.5)C=S(I)

IF(I.EQ.6)C=S(I)

RHOL=(SOL(I)+H2O(I)+C)/((LSOL(I)+C)/4)+(H2O(I)/8)

R=S(I)

IF(I.EQ.5) GO TO 1

IF(I.EQ.6) GO TO 1

RHOS=(PI(I)+R)/((DI(I)/SGORE)+(P/SGSOL))

GO TO 2

1 RHOS=SGORE

2 V=(.0251*(((D(K)*DENS(I))/(12.*VIS(I)*.000672))**.775)*(((RHOS-RHO
1L)/F+1L)*32.17*(1./304.8)))**.775)

C

C IF MINIMUM VELOCITY NOT EXCEEDED RESIZE LINE

C

IF(V-VEL(I))3,3,4

4 K=K-1

IF(K.EQ.0) GO TO 13

VEL(I)=(575.*INITIAL(I))/DF(I(I)+1)*((H)-*21+3.14(I))

GO TO 2

13 K=K+1

3 CONTINUE

RETURN

END

SUBROUTINE WASH(SCO,SULT,B,F)

WATER BALANCE OVER FILTER

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

SOL(14)=F*(30.-SULT)

SOL(13)=SOL(10)-SOL(14)

S(15)=SOL(14)/B

S(10)=S(14)+S(15)

H2O(10)=(S(10)+SOL(10))*(TOTAL(30)/(1.-TOTAL(30)))

H2O(13)=H2O(10)

RETURN

END

SUBROUTINE XINTER(F,E,D,C,B,A)

C
C THIS ROUTINE INTERPOLATES BETWEEN TWO POINTS ASSUMING
C THE CURVE BETWEEN THESE POINTS CAN BE LINEARISED
C

$A = D + ((E - D) / (C - B)) * (F - B)$

RETURN

END

SUBROUTINE XMIXER(N3,N4,MIX,MX)

AGITATOR DESIGN BASED ON JUNE 5, 1975

COMMON DI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DPI(40),DIL(40),VEL(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIOPT(40),CAP(10),HP(20),STORE(30),BELT(5,20)

COMMON SOLID(25),SUSCL(25),CHRT(25),VISCONS(25,2),CRYT(25),TEMP7(2)

COMMON CON(2,7),HE(25),XNT(17,2),VISN(50,2),VOL(10,3),SETDIA(10,2)

COMMON EQUIP(3,12,2),UNITCT(40,2),XMIX(20)

V=(TOTAL(N3)*XMIX(1))/((3.1416*XMIX(2)*END(N3)))

VOL(N4,1)=V*7.48

VOL(N4,2)=((14.4V)/(3.1416*XMIX(3)))**(.75/.25)

VOL(N4,3)=VOL(N4,2)*XMIX(3)

XMIX(20)=VOL(N4,2)*XMIX(4)

IF(MIX.EQ.1) GO TO 2

1 XMIX(19)=XMIX(11)/(3.1416*XMIX(20)*60.)

REYNO=(DENS(N3)*XMIX(19)*((1-XNT(N3))**.2))/(VIS(N3)*.0001)

GO TO 3

2 REYNO=XMIX(11)

XMIX(19)=(XMIX(11)*VIS(N3)*.00017)/(REYNO**(.47)/(REYNO**(.47)+1))

3 DO 4 IPN=1,2

IF(PEX(IPN,7)-REYNO)4,5,6

4 CONTINUE


```
5 PN=REX(IPN,8)
```

```
30 TO 7
```

```
6 CALL XITIFF(REFNO,REX(IPN,5),REX(IPN-1,3),REX(IPN,7),REX(IPN-1,7),  
1PN)
```

```
7 HP(MX)=(PN*DENS(N3)*(XMIX(19)**3)*(XMIX(20)**5)*XMIX(5))/(32.17*55  
10.)
```

```
XMIX(20)=XMIX(20)*12.
```

```
XMIX(14)=XMIX(14)*XMIX(20)
```

```
XMIX(15)=XMIX(9)*XMIX(20)
```

```
XMIX(16)=XMIX(7)*VCL(N4,2)*12.
```

```
XMIX(19)=XMIX(19)*60.
```

```
RETURN
```

```
END
```


SUBROUTINE XMU

C CALCULATES STREAM VISCOSITIES

COMMON OI(30),S(30),SOL(30),H2O(30),TOTAL(30),TEMP(30),TEMP2(3)

COMMON HDUTY(2),DUMP(30),VIS(40),DP(40),DP1(40),DP2(40),VIR(40)

COMMON REX(50,8),Q(20),D(12),DNB(12),PMET(13),SPHEAT(13,2),CP(5)

COMMON DENS(40),DIUPT(40),CAP(10),HP(20),STORE(30),BFLT(5,20)

COMMON SOLD(25),SGSOL(25),S_H2O(30),V_H2O(30),V_H2O2(30),TEMP2(3)

DO 1 I=2,27

M=2

IF(SOL(I).GE.H2O(I))M=1

IF(I.EQ.2) GO TO 2

IF(I.EQ.7) GO TO 3

IF(I.EQ.17) GO TO 4

IF(I.EQ.19) GO TO 1

T=TEMP(I)

N=I

CALL PHASEV (M,A1,T)

VIR(N)=A1

GO TO 1

2 DO 2 JT=1,3

T=TEMP2(JT)

JURD=JT+29

CALL PHASEV(M,A9,T)

VIS(NURD)=A9

5 CONTINUE

GO TO 1

3 DO 6 JTR=1,2

T=TEMP7(JTR)

NUB=JTR+27

CALL PHASEV(M,A42,T)

VIS(NUR)=A42

6 CONTINUE

1 CONTINUE

RETURN

END

APPENDIX V

PLANT MATERIAL BALANCE AND EXTRACTION TEMPERATURE DERIVATIONS

The important streams in the solvent extraction plant for the material balance calculation are illustrated in figure 15. The symbols shown are used in the following derivations.

Basis : 1 lb. ore feed to unit.

Given Information:

- x : weight fraction of sulphur in ore
- y : weight fraction of gypsum etc. in ore
- z : weight fraction of water in ore
- g : weight fraction of solvent retained on gangue, expressed on a sulphur free basis
- r : weight fraction of solvent occluded on gangue
- T_c : sulphur crystallisation temperature
- T_E : estimated extraction temperature
- α : solvent-ore slurry maximum solids content
- β : solubility of sulphur in solvent for given temperature.

Mathematical Derivation

The first step in the material balance calculation is to obtain an estimate of the size of the solvent make-up and recycle streams. This is achieved by determining the solvent losses in the gangue and product streams.

$$F = B_b + D_r \quad \dots(8)$$

The solvent lost in the tailings, assuming complete dissolution of the sulphur from the ore, is given by:

$$Bb = \frac{(1 - x)g}{1 - g} \quad \dots(9)$$

This quantity of solvent, being at the estimated extraction temperature T_E , will contain dissolved sulphur. From the solubility relationship, the amount of sulphur dissolved can be calculated.

$$\beta_{T_E} = \frac{Ba}{Ba + Bb} \quad \dots(10)$$

$$\text{thus } Ba = \frac{\beta_{T_E} Bb}{1 - \beta_{T_E}}$$

Hence the sulphur reporting in the product stream can be found

$$Dq = x - Ba \quad \dots(11)$$

The solvent losses in the product are

$$Dr = \frac{(x - Ba) r}{1 - r} \quad \dots(12)$$

The maximum solids content of the slurry is specified as α . Knowing this parameter the size of the solvent recycle stream can be evaluated. For this calculation it is assumed that any sulphur in this recycle stream is in the solid form. This is not true, of course, but serves to simplify the arithmetic.

$$\frac{(Es + x + y + z)(1 - \alpha)}{\alpha} = F + Et \quad \dots(13)$$

$$\text{since } x + y + z = 1$$

$$\text{and } \frac{Es}{Es + Et} = \beta_{T_c}$$

equation (13) can be rewritten as

$$\left(\frac{Et \beta_{T_c}}{(1 - \beta_{T_c})} + 1 \right) (1 - \alpha) = \alpha F + Et \alpha \quad \dots(14)$$

$$\text{letting } \frac{\beta_{T_c}}{1 - \beta_{T_c}} = \frac{1}{\gamma} \quad \text{and rearranging}$$

$$Et = \frac{\gamma(1 - \alpha(F + 1))}{(\alpha(\gamma + 1) - 1)} \quad \dots(15)$$

As F is known for the initial extraction temperature estimate, equation 15 can be solved for the solvent recycle quantity, Et .

Using the information a new extraction temperature can be found through the solubility relationship.

$$\beta'_{T_E} = \frac{Es + x}{x + y + z + Es + Et + F} \quad \dots(16)$$

An iterative solution technique is then employed until no change in the extraction temperature estimation takes place.

Once this temperature has been determined, all the other unknown quantities shown in figure 15 can be calculated. This completes the material balance derivation.

If the extraction temperature is calculated to be above 200°F for

the given slurry solids content and ore sulphur concentration, it must be reduced since there is a possibility of steam formation in the washing operation. This conflicts with the design philosophy and should be avoided. A high ore sulphur content is responsible for extraction temperatures being above 200°F. To lower this temperature, the slurry solids content must therefore be reduced. This is achieved by an iterative process in which the slurry concentration is lowered in stages until the extraction temperature is below 200°F.

The above description outlines the calculation procedure followed by the plant simulation program. It forms the basis of the subroutine EXTEMP.

APPENDIX VI

PLANT OPERATING ALTERNATIVES

In the chapter discussing plant optimisation reference was made to plant operations for a case with no partial solvent cooler and a case with no solvent recovery from the thickened tailings. These situations are covered in this appendix.

Case I : No partial solvent cooler.

Taking the optimum plant design specification and recalculating the cost details, it can be shown that the production costs become prohibitive.

The following notes summarise these calculations:

Extra cooling water required:

heat to be removed i.e. E-2 heat duty = 19.61×10^6 BTU/hr

water needed (initial temperature 38.0°F

$$\begin{aligned} \text{and outlet temperature } 73.5^{\circ}\text{F}) &= \frac{19.61 \times 10^6}{35.5 \times 1} \\ &= 5.54 \times 10^5 \text{ lbs/hr} \end{aligned}$$

annual cost for this quantity of water:

$$\begin{aligned} &\frac{5.54 \times 10^5 \times 7.48 \times 8000 \times 0.20}{62.4 \times 1000} \\ &= \underline{\underline{\$106500}} \end{aligned}$$

capital saved by not installing heat exchanger, E-2: \$88543

annual reduction in maintenance charges : \$ 3540

Extra heat required by solvent to attain desired extraction temperature:

$$\begin{aligned}
 & 19.61 \times 10^6 \text{ BTU/hr} \\
 \text{annual cost} &= \frac{19.61 \times 10^6 \times 0.555 \times 8000}{913 \times 1000 \times 0.75} \\
 &= \underline{\underline{\$127000}}
 \end{aligned}$$

Revised furnace cost:

$$\begin{aligned}
 \text{total heat duty} &= 11.78 \times 10^6 + 19.61 \times 10^6 \\
 &= 31.39 \times 10^6 \text{ BTU/hr}
 \end{aligned}$$

hence revised cost (from Drayer (31)):

$$= \underline{\underline{\$70000}}$$

ignoring extra charges for larger water pumps and pipes revised optimum plant cost becomes:

$$\begin{aligned}
 & 366350 - (88543 + 34448) + 70000 \\
 &= \underline{\underline{\$313360}}
 \end{aligned}$$

$$\text{total capital investment} : \underline{\underline{\$1.468 \times 10^6}}$$

Revised operating costs:

$$\begin{aligned}
 \text{cooling water} &: 40800 + 106500 = \$147300 \\
 \text{natural gas} &: 69500 + 127000 = \$196500 \\
 \text{maintenance} &: 68730 + 2800 \\
 &\quad -(3540 + 1380) = \$ 66610
 \end{aligned}$$

therefore total annual direct manufacturing cost:

$$\begin{aligned}
 & 938100 - 68730 + 66610 + 106500 + 127000 \\
 &= \underline{\underline{\$1169480}}
 \end{aligned}$$

$$\text{manufacturing price per ton product} = \underline{\underline{\$23.15}}$$

Case II : No solvent recovery from thickened tailings

For this case, it is assumed that all of the kerosene occluded on the tailings that enter the lower section of the settler, S-1, remain associated with the ore wastes.

From the material balance, again for the optimum plant, the solvent occluded amounts to 4425 lbs/hr.

The annual cost to replace this quantity of kerosene is

$$= \frac{4425 \times 7.48 \times 0.133 \times 8000}{62.4 \times 0.79} = \underline{\underline{\$715000}}$$

Hence revised operating costs:

total direct production cost	:	\$1955715
production cost per ton product	:	<u>\$29.30</u>

APPENDIX VII

ROTARY VACUUM FILTER DESIGN PROCEDURE

As indicated in the filtration experiments section of chapter V, the major resistance to the filtration of the sulphur slurry was provided by the filter medium. The specific cake resistance of sulphur could be ignored in any experimental calculation.

This appendix discusses the modifications made to the vacuum filter design equations, presented by Peters and Timmerhaus (63), to take account of this observation.

The integrated form of equation 6, Appendix III, assuming K is zero, for the limits $V = 0$ to V and $\theta = 0$ to θ , is:

$$\theta = \frac{\mu R_m V}{A g_c \Delta P} \quad \dots(17)$$

For a rotary drum type vacuum filter, having an area of $A \text{ ft}^2$, a drum submergence fraction of F_f and a rotation speed of $N_R \text{ r.p.m.}$, the above equation can be rewritten as:

$$V_f = \frac{(A \Delta P F_f)}{(\mu_f R_m N_R)} \quad \frac{\text{ft}^3}{\text{rev.}} \quad \dots(18)$$

where N_R : drum rotation speed revs. per min.

f : filtrate designation

Since the weight of sulphur cake produced per hour, W , is known from the material balance calculations, the drum filter area can be found from:

$$W = V_f N_R w = \frac{(AF_f \Delta P w)}{(R_m \mu_f)} \frac{\text{lbs}_m}{\text{hr}} \quad \dots (19)$$

where w = weight of cake per volume of filtrate, lbs_m/ft^3

Assuming the specific cake resistance to air suction is also negligible, the volume of air required to dry the cake can be established from:

$$V_a N_R = \frac{(AF_a \Delta P)}{(R_m' \mu_a)} \frac{\text{ft}^3}{\text{hr}} \quad \dots (20)$$

where a : air designation

R_m' : air suction filter media resistance, $(\text{hr}/\text{ft})^2$

F_a : fraction drum area available for air suction

Assuming $R_m = R_m'$, equations 19 and 20 are used for preliminary sizing estimates in the plant design subprogram VACF, page 268.

APPENDIX VIII

Tables

EXPERIMENTAL RESULT TABULATIONS

RUN NO.	SAMPLE TEMPERATURE	DEG.F.	SAMPLING TIME	CORRECTION FACTORS		PERCENTAGE FACTORS	
				FOR TIME = TS	FOR TIME = TAVG	SPRDS	PERCENTAGE
			TS SECS.				
1		147.0	34.0	0.999386	0.999377	0.0	0.0
2		146.0	33.0	0.999036	0.999014	0.0	0.0
3		145.0	31.0	0.999036	0.999014	0.0	0.0
4		164.0	31.0	0.999368	0.999302	0.0	0.0
5		163.0	34.0	0.999036	0.999014	0.0	0.0
6		164.0	34.0	0.999036	0.999014	0.0	0.0
7		171.0	34.0	0.999036	0.999014	0.0	0.0
8		171.0	32.0	0.999821	0.999756	0.0	0.0
9		170.0	34.0	0.999036	0.999014	0.0	0.0
10		192.0	29.0	0.998731	0.998871	0.0	0.0
11		192.0	29.0	0.998770	0.998609	0.0	0.0
12		74.0	33.0	0.999892	0.999837	0.0	0.0

TABLE 1 WEIGHING CORRECTION FACTORS TO ALLOW FOR SOLVENT EVAPORATION I

TEMPERATURE DEG. F.	TS SECS.	CORRECTED TIME FOR TIME =		CORRECTED TIME FOR TIME =		TAVG
		TS				
12 74.0	34.0	0.999982	0.0	0.999979	0.0	
14 110.0	34.0	0.999842	0.0	0.999839	0.0	
14 110.0	35.0	0.999537	77.2	0.999542	60.9	
15 130.0	31.0	0.999477	0.0	0.999429	0.0	
15 130.0	34.0	0.999571	0.0	0.999564	0.0	
15 130.0	36.0	0.999608	0.0	0.999712	0.0	
15 130.0	40.0	0.999548	31.3	0.999639	18.0	
16 177.0	38.0	0.998719	0.0	0.998825	0.0	
16 177.0	32.0	0.998453	0.0	0.998360	0.0	
16 176.0	35.0	0.998525	45.0	0.998541	29.6	
16 175.0	30.0	0.998446	0.0	0.998274	0.0	

TABLE 1 WEIGHING CORRECTION FACTORS TO ALLOW FOR SOLVENT EVAPORATION IN THE SULPHUR SULPHIDE

100%
 100%
 100%

100%
 100%
 100%

100%
 100%
 100%

100%
 100%
 100%

100%
 100%
 100%

100%
 100%
 100%

100%
 100%
 100%

100%
 100%
 100%

100%
 100%
 100%

10 176.0 28.0 0.003045 0.0 0.007045 0.0

17 101.0 24.0 0.003063 0.0 0.003063 0.0

17 101.0 20.0 0.003272 0.0 0.003075 0.0

17 102.0 21.0 0.007540 0.0 0.007000 0.0

17 102.0 40.0 0.003049 0.0 0.003030 0.0

17 100.0 32.0 0.003046 0.0 0.003046 0.0

17 103.0 30.0 0.003011 0.0 0.003010 0.0

17 103.0 34.0 0.003011 0.0 0.003010 0.0

17 103.0 34.0 0.003011 0.0 0.003010 0.0

AVG. 200 SAMPLES TIME WAS 24.6 SEC.

TABLE 1. WEIGHT OF CORRELATION FACTORS TO AID FOR
SOLVENT EVALUATION IN THE SOLID-STATE ESTIMATION

SUN NO.	OVER- TEMPERATURE DEG.F.	OVER- TIME T MINS.	CORRECTION FACTORS	PERCENTAGE LOSS	CORRECTION REMARKS TIME
12	200.0	47.0	0.994031	4.3	45.0
13	200.0	43.0	0.974231	5.2	40.0
13	200.0	45.0	0.962136	4.5	40.0
13	200.0	41.0	0.944447	4.5	40.0
13	200.0	60.0	0.946397	4.4	50.0
13	200.0	60.0	0.943167	4.4	50.0
13	200.0	50.0	0.893976	2.4	45.0
14	200.0	50.0	0.904415	2.7	45.0
14	200.0	50.0	0.957647	3.1	45.0
14	200.0	50.0	0.933145	3.0	45.0
14	200.0	60.0	0.939463	2.8	50.0

FOR SULPHUR SUBLIMATION

DYEING TIME MINS.	TEMPERATURE DEG. F.	SOLUTION		SULPHUR		PERCENTAGE ERROR	
		CMS.	CMG.	CMS.	CMG.	S/CM.	CMG.
40.0	101.0	3.723	3.723	0.172	0.172	0.046	4.0
50.0	101.0	3.723	3.723	0.172	0.172	0.046	4.0
60.0	102.0	2.423	2.423	0.100	0.100	0.045	4.6
70.0	102.0	3.723	3.723	0.172	0.172	0.046	4.0
80.0	102.0	3.265	3.265	0.149	0.149	0.046	4.1
90.0	102.0	3.226	3.226	0.145	0.145	0.045	4.1

TABLE 2. SULPHUR SOLUBILITY IN PEROSPER AT 102.0 DEG. F.

Drying Time mins	Temperature deg. f.	Sulphur		Sulphur solution		Sulphur s/gm. sol'n.	Percentage sol'n.
		gms.	gms.	gms.	gms.		
0.5	176.0	0.000	0.000	0.000	0.000	0.000	0.0
1.0	176.0	0.000	0.000	0.000	0.000	0.000	0.0
1.5	176.0	0.000	0.000	0.000	0.000	0.000	0.0
2.0	176.0	0.000	0.000	0.000	0.000	0.000	0.0
2.5	176.0	0.000	0.000	0.000	0.000	0.000	0.0
3.0	176.0	0.000	0.000	0.000	0.000	0.000	0.0
3.5	176.0	0.000	0.000	0.000	0.000	0.000	0.0
4.0	176.0	0.000	0.000	0.000	0.000	0.000	0.0

TABLE 4. SULPHUR SOLUBILITY IN PEROSINE AT 176.0 DEG. F.

SAMPLE DRYING TIME	SOLUTION TEMPERATURE	WEIGHTS		SULPHUR DISSOLVED PERCENTAGE	
	DEG.F.	GMS.	GMS.	GMS. S/GM. SOLN.	
70.0	177.0	3.057	0.107	0.035	4.4
90.0	177.0	3.057	0.106	0.035	4.4
110.0	177.0	3.057	0.106	0.035	4.4
130.0	177.0	3.249	0.112	0.034	4.3
150.0	177.0	3.057	0.106	0.035	4.4
170.0	177.0	3.120	0.100	0.034	4.3
190.0	176.0	3.750	0.130	0.037	4.1
210.0	176.0	3.750	0.135	0.036	4.2
230.0	176.0	3.750	0.132	0.036	4.3

ANALY- TIME	TEMPERATURE DEG. C.	WATER GMS.	WATER GMS.	WATER GMS.	WATER GMS.
TIME	DEG. C.	WATER GMS.	WATER GMS.	WATER GMS.	WATER GMS.

40.0	151.0	3.701	0.085	0.023	4.6
50.0	152.0	3.701	0.085	0.023	4.6
60.0	152.0	3.701	0.085	0.023	4.6
70.0	152.0	3.701	0.085	0.023	4.6
80.0	152.0	3.701	0.085	0.023	4.6
90.0	152.0	3.701	0.085	0.023	4.6
100.0	152.0	3.701	0.085	0.023	4.6
110.0	152.0	3.701	0.085	0.023	4.6
120.0	152.0	3.701	0.085	0.023	4.6
130.0	152.0	3.701	0.085	0.023	4.6
140.0	152.0	3.701	0.085	0.023	4.6
150.0	152.0	3.701	0.085	0.023	4.6
160.0	152.0	3.701	0.085	0.023	4.6
170.0	152.0	3.701	0.085	0.023	4.6
180.0	152.0	3.701	0.085	0.023	4.6
190.0	152.0	3.701	0.085	0.023	4.6
200.0	152.0	3.701	0.085	0.023	4.6
210.0	152.0	3.701	0.085	0.023	4.6
220.0	152.0	3.701	0.085	0.023	4.6
230.0	152.0	3.701	0.085	0.023	4.6
240.0	152.0	3.701	0.085	0.023	4.6
250.0	152.0	3.701	0.085	0.023	4.6
260.0	152.0	3.701	0.085	0.023	4.6
270.0	152.0	3.701	0.085	0.023	4.6
280.0	152.0	3.701	0.085	0.023	4.6
290.0	152.0	3.701	0.085	0.023	4.6
300.0	152.0	3.701	0.085	0.023	4.6

TABLE 5. SOLUBILITY IN KETOSOL AT 152.0 DEG. C.

TABLE 6. SULPHUR SOLUBILITY IN KEROSENE AT 130.0 DEG.

SAMPLE DYEING TIME	SOLUTION TEMPERATURE DEG.F.	SOLUTION		SULPHUR		SULPHUR		PERCENTAGE
		GMS.	GMS.	GMS.	GMS.	GMS.	S/GM. SOLN.	
40.0	130.0	3.574	0.054	0.015				5.4
60.0	130.0	3.574	0.047	0.012				5.7
80.0	130.0	3.574	0.040	0.008				5.8
90.0	130.0	3.574	0.039	0.011				6.1
100.0	130.0	3.574	0.027	0.010				6.2
120.0	130.0	3.574	0.020	0.008				6.2
140.0	130.0	3.574	0.018	0.008				6.2
160.0	130.0	3.574	0.016	0.008				6.2
180.0	130.0	3.574	0.015	0.008				6.2
200.0	130.0	3.574	0.014	0.008				6.2
220.0	130.0	3.574	0.013	0.008				6.2
240.0	130.0	3.574	0.012	0.008				6.2
260.0	130.0	3.574	0.011	0.008				6.2
280.0	130.0	3.574	0.010	0.008				6.2
300.0	130.0	3.574	0.009	0.008				6.2
320.0	130.0	3.574	0.008	0.008				6.2
340.0	130.0	3.574	0.007	0.008				6.2
360.0	130.0	3.574	0.006	0.008				6.2
380.0	130.0	3.574	0.005	0.008				6.2
400.0	130.0	3.574	0.004	0.008				6.2
420.0	130.0	3.574	0.003	0.008				6.2
440.0	130.0	3.574	0.002	0.008				6.2
460.0	130.0	3.574	0.001	0.008				6.2
480.0	130.0	3.574	0.000	0.008				6.2
500.0	130.0	3.574	0.000	0.008				6.2

SAMPLE TIME MINS	SOLUTION DEG.F.	WEIGHTS		SULPHUR DISSOLVED	
		GMS.	GMS.	GMS. S/CM. SOLN.	PERCENT
55.0	130.0	4.577	0.070	0.015	4.0
60.0	130.0	4.575	0.070	0.015	5.7
65.0	130.0	4.575	0.070	0.015	5.1
70.0	130.0	4.575	0.070	0.015	5.0
75.0	130.0	4.575	0.070	0.015	5.0
80.0	130.0	4.581	0.070	0.015	5.5
85.0	130.0	4.581	0.070	0.015	5.7
90.0	130.0	4.581	0.070	0.015	5.0
95.0	130.0	4.581	0.070	0.015	5.0
100.0	130.0	4.577	0.070	0.015	5.0

TABLE 5. SULPHUR SOLUBILITY IN KEROSENE AT 130.0 DEG.F.

TABLE 7. SULPHUR SOLUBILITY IN PEPERONE AT 110.0 DEG.F.

DRYING TIME	TEMPERATURE	SOLUTION	SULPHUR	PERCENTAGE FROM
50.0	110.0	5.112	0.052	5.4
75.0	110.0	5.112	0.046	5.7
100.0	110.0	5.112	0.041	5.8
125.0	110.0	5.112	0.035	5.9
150.0	110.0	4.266	0.040	6.0
175.0	110.0	4.266	0.035	6.1
200.0	110.0	4.266	0.030	6.2
225.0	110.0	4.266	0.024	6.3
250.0	110.0	4.266	0.020	6.4
275.0	110.0	4.266	0.015	6.5
300.0	110.0	4.266	0.010	6.6
325.0	110.0	4.266	0.005	6.7
350.0	110.0	4.266	0.000	6.8

TABLE 2. SOLUBILITY IN ETHYLENE AT 0°C. DEGREE

TEMPERATURE, °C.	SOLUBILITY, GMS. S/C.M. SOLN.	DEGREE
41.0	3.343	0.021
56.0	3.343	0.019
71.0	3.343	0.012
86.0	3.343	0.004
101.0	4.045	0.025
116.0	3.356	0.026
131.0	3.356	0.024
146.0	3.701	0.024

TABLE 3. SOLUBILITY IN ETHYLENE AT 0°C. DEGREE

COOLING CURVE TEMPERATURE SOLUTION SULPHUR PERCENTAGE

MIN.	DEG.F.	GMS.	GMS.	GMS. S/GM. SOLN.	PERCENTAGE
47.0	94.0	3.953	0.025	0.006	7.6
62.0	94.0	3.953	0.021	0.005	8.4
77.0	94.0	3.953	0.016	0.004	9.2
93.0	94.0	3.793	0.022	0.006	12.6
53.0	94.0	3.793	0.013	0.005	7.6
68.0	94.0	3.793	0.010	0.003	8.4
83.0	94.0	3.793	0.012	0.003	9.2
45.0	94.0	4.101	0.025	0.016	12.6
60.0	94.0	4.101	0.020	0.012	12.6
75.0	94.0	4.101	0.015	0.009	12.6
90.0	94.0	4.101	0.010	0.006	12.6

SAMPLE NAME	SOLUTION TEMPERATURE	WEIGHTS		SULPHUR DISSOLVED
		GMS.	GMS.	
MGMS	DEG.F.	GMS.	GMS.	GMS. S/GM. SOLN.
1042	70.7	1.000	0.000	0
1043	70.7	0.000	0.000	0
1044	70.7	0.000	0.000	0

TABLE 3. SULPHUR SOLUBILITY IN KEROSENE AT 70.0 DEG.F.

TIME MINS	DEG.F.	CM.S.	CM.S.	CM.S. S/CM. S/LM.	FD.000
100	70.0	2.0	2.0	2.0	0
200	70.0	2.0	2.0	2.0	0
300	70.0	2.0	2.0	2.0	0
400	70.0	2.0	2.0	2.0	0
500	70.0	2.0	2.0	2.0	0

TABLE 2. SOLUBILITY IN FETTERIE AT 74.0 DEG.F.

Sample ore #	2, 1	2, 2	3*	4, 1
wt. % sulphur	15.5	18.5	0.0	40.2
wt. % water	8.1	9.2	11.2	8.7
wt. % gypsum etc.	76.4	72.3	88.8	51.1

*average of three tests

Table 10. Alberta ore major constituents.

Sample #		wt. % sulphur	wt. % gypsum etc.
1,	1	22.7	77.3
	2	35.0	65.0
	3	15.2	84.8
2,	1	16.9	83.1
	2	13.8	86.2
	3	12.5	87.5
	4	24.1	75.9
	5	20.0	80.0
	6	24.3	75.7
	7	18.0	82.0
	8	20.9	79.1
	9	20.4	79.6
	10	8.0	92.0
	11	15.1	84.9
	12	19.0	81.0
3		0.0	100.0
4,	1	44.0	56.0
5,	1	39.1	60.9
	2	50.5	49.5
	3	44.6	55.4
	4	53.5	46.5

Table 11. Alberta ore sulphur and gypsum contents on water free basis.

component	kerosene wt %	sulphur wt %	water wash ratio*
unwashed cake	7.8	92.2	0
	7.6	92.4	0
water washed cake	2.7	97.3	2.86
	2.9	97.1	2.86
	1.9	98.1	7.65
	1.6	98.4	7.65

*water wash ratio is defined as the amount of water used in washing a unit weight of sulphur cake.

Table 12. Sulphur product purity test results.

SAMPLE STIRRING TIME	SAMPLE TEMPERATURE DEG.F.	WEIGHTS		SULPHUR DISSOLVED	
		SOLUTION GMS.	SULPHUR GMS.	S/GM. SOLN.	PERCENTAGE ERROR
2.0	130.0	0.776	0.004	0.006	28.1
2.0	130.0	0.919	0.005	0.006	23.3
4.0	130.0	2.501	0.030	0.012	7.0
8.0	131.0	2.559	0.039	0.015	6.2
16.0	132.0	2.807	0.046	0.016	5.7

TABLE 13 SULPHUR DISSOLUTION RATE EXPERIMENTAL RESULTS FOR

SAMPLE STIRRING TIME	TEMPERATURE DEG. F.	SOLUTION		SULPHUR		GMS. S/GM. SOLN.	PERCENTAGE ERROR
		GMS.	DEG. F.	GMS.	DEG. F.		

32.0	135.0	2.488		0.036		0.015	6.3
32.0	130.0	2.748		0.037		0.013	6.3
48.0	130.0	2.564		0.028		0.011	7.2
48.0	125.0	2.915		0.025		0.008	7.7
60.0	127.0	2.899		0.017		0.006	9.6
60.0	127.0	2.483		0.019		0.007	9.2

TABLE 13 SULPHUR DISSOLUTION RATE EXPERIMENTAL RESULTS FOR
SYNTHETIC ORE AT 127.0 DEG. F.

SAMPLE STIRRING TIME	SAMPLE TEMPERATURE DEG.F.	WEIGHTS		SULPHUR GMS.	GMS. S/GM. SOLN.	SULPHUR DISSOLVED PERCENTAGE BY WT.
		SOLUTION	SULPHUR			
1.0	143.0	3.853	0.011	0.003	0.003	0.00
1.0	143.0	3.817	0.005	0.001	0.001	0.00
3.0	143.0	3.883	0.007	0.001	0.001	0.00
2.0	144.0	2.486	0.011	0.004	0.004	13.1
4.0	145.0	3.807	0.001	0.001	0.001	0.00
4.0	145.0	3.818	0.001	0.001	0.001	0.00
8.0	145.0	3.851	0.005	0.005	0.005	0.00
5.0	145.0	3.800	0.005	0.005	0.005	0.00

TABLE 16. SULPHUR DISSOLUTION RATE IN SYNTHETIC ORE AT 143.0 DEG.F.

SAMPLE STIRRING TIME	SAMPLE TEMPERATURE DEG. F.	SOLUTION		SULPHUR		GMS. S/GM. SOLN.	PERCENTAGE SULPHUR
		GMS.	DEG. F.	GMS.	DEG. F.		
14.0	147.0	3.867	147.0	0.081	147.0	0.021	4.7
16.0	147.0	3.867	147.0	0.081	147.0	0.021	4.7
32.0	147.0	4.161	147.0	0.087	147.0	0.021	4.8
32.0	147.0	3.831	147.0	0.081	147.0	0.021	4.7
45.0	147.0	4.187	147.0	0.083	147.0	0.020	4.7
45.0	147.0	3.140	147.0	0.053	147.0	0.017	5.4
60.0	148.0	3.315	148.0	0.055	148.0	0.017	5.3
60.0	148.0	4.267	148.0	0.080	148.0	0.019	4.7

TABLE 16. SYNTHETIC ORE AT 148.0 DEG. F.

SAMPLE STANDING TIME	SAMPLE TEMPERATURE	WEIGHTS		SULPHUR DISSOLVED	
		SOLUTION	SOLVENT	GMS. S/GM. SOLN.	GMS. S/GM. SOLN.
MINS	DEG.F.	GMS.	GMS.		
2.0	150.0	2.000	0.000	0.018	5.4
3.0	150.0	2.000	0.000	0.018	5.3
4.0	150.0	2.000	0.000	0.021	5.1
4.0	150.0	2.358	0.048	0.020	5.6
8.0	152.0	2.666	0.057	0.021	5.3
16.0	152.0	1.393	0.030	0.022	6.9
16.0	152.0	1.393	0.030	0.022	6.9

TABLE 15 SULPHUR DISSOLUTION RATE EXPERIMENTAL RESULTS FOR
SYNTHETIC ORE AT 151.0 DEG.F.

SAMPLE STIRRING TIME	SAMPLE TEMPERATURE	SOLUTION		SULPHUR		GMS. S/GM. SOLN.	PERCENTAGE ERROR
		DEG.F.	GMS.	GMS.			
32.0	152.0	2.588	0.049	0.019		5.6	
32.0	152.0	2.123	0.046	0.022		5.7	
45.0	150.0	2.978	0.062	0.021		5.1	
45.0	150.0	2.888	0.041	0.014		6.0	
60.0	151.0	2.228	0.041	0.018		6.0	
60.0	151.0	2.245	0.041	0.018		6.0	

TABLE 15 SULPHUR DISSOLUTION RATE EXPERIMENTAL RESULTS FOR
SYNTHETIC ORE AT 151.0 DEG.F.

SAMPLE STIRRING TIME MINS	SAMPLE TEMPERATURE DEG.F.	WEIGHTS		SULPHUR DISSOLVED PERCENTAGE	
		SOLUTION GMS.	SULPHUR GMS.	GMS. S/GM. SOLN.	
1.0	168.0	2.506	0.017	0.007	9.6
2.0	167.0	2.231	0.019	0.008	9.1
3.0	166.0	2.161	0.021	0.010	9.8
4.0	165.0	2.090	0.022	0.010	9.7
5.0	164.0	2.017	0.023	0.011	9.4
8.0	171.0	2.677	0.057	0.021	5.3

TABLE 15 SULPHUR DISSOLUTION RATE EXPERIMENTAL RESULTS FOR
SYNTHETIC OBF AT 173.0 DEG. C.

SAMPLE STIRRING TIME MINS.	SAMPLE TEMPERATURE DEG. F.	WEIGHTS		SULPHUR DISSOLVED	
		SOLUTION GMS.	SULPHUR GMS.	S/GM. SOLN.	PERCENTAGE FREE
20.0	170.0	0.000	0.000	0.025	4.8
30.0	170.0	0.000	0.067	0.028	5.0
35.0	170.0	0.075	0.078	0.028	4.7
37.0	170.0	0.091	0.078	0.026	4.8
45.0	170.0	0.100	0.091	0.027	4.9
50.0	170.0	0.116	0.091	0.027	4.8
55.0	170.0	0.115	0.091	0.026	4.8

TABLE II. SULPHUR DISSOLUTION RATE EXPERIMENTAL RESULTS FOR
SYNTHETIC ORE AT 170.0 DEG. F.

TABLE 17. SULPHUR DISSOLUTION RATE EXPERIMENTAL. SYNTHETIC ORF AT 188.0 DEG.F.

SAMPLE STIRRING TIME MINS	SAMPLE TEMPERATURE DEG.F.	WEIGHTS		GMS. S/GM. SOLN.	SULPHUR DISSOLVED PERCENTAGE
		SOLUTION GMS.	SULPHUR GMS.		
1.0	184.0	1.148	0.007	0.006	19.3
1.0	184.0	1.148	0.007	0.006	11.0
2.0	182.0	2.116	0.010	0.004	18.8
2.0	182.0	2.578	0.007	0.003	18.3
4.0	182.0	2.116	0.007	0.003	18.0
4.0	188.0	2.760	0.056	0.020	5.3
1.0	187.0	2.200	0.007	0.003	18.0
1.0	187.0	2.600	0.007	0.003	18.0

SAMPLE STANDING TIME	SAMPLE TEMPERATURE	DETERMINING SOLUTION	DETERMINING SOLUBLE	GMS. S/GM. SOLN.	GRAVIMETRIC PERCENT
MINS	DEG.F.	GMS.	GMS.		
16.0	187.0	2.719	0.075	0.028	4.8
16.0	187.0	2.703	0.079	0.029	4.7
32.0	187.0	2.687	0.074	0.028	4.7
32.0	188.0	2.620	0.077	0.029	4.8

TABLE 17 SULPHUR DISSOLUTION RATE EXPERIMENTAL RESULTS FOR
SYNTHETIC ORE AT 180.0 DEG.F.

SAMPLE STANDING TIME	SAMPLE TEMPERATURE DEG. F.	WEIGHTS		SULPHUR DISSOLVED	
		SOLUTION GMS.	SULPHUR GMS.	GMS. S/GM. SOLN.	PERCENTAGE CARBON
1.0	160.0	3.069	0.041	0.014	6.0
1.0	160.0	1.475	0.012	0.008	12.4
2.0	160.0	2.000	0.021	0.011	5.8
2.0	160.0	2.000	0.022	0.011	5.7
4.0	160.0	2.907	0.065	0.022	5.0
4.0	160.0	2.907	0.064	0.021	5.1
8.0	160.0	2.959	0.073	0.025	4.8
8.0	160.0	2.424	0.058	0.024	5.2

TABLE 1. SULPHUR DISSOLUTION AT 160°F. IN CARBON
ALBERTA OIL FIELD NO. 1000

SAMPLE STIRRING TIME, MINS.	SAMPLE TEMPERATURE DEG.F.	WEIGHTS		SOLUTION OF SULPHUR	
		SOLUTION GMS.	SULPHUR GMS.	GMS. S/GM. SOLN.	PERCENTAGE
16.0	162.0	8.111	0.245	0.023	1.1
16.0	162.0	2.362	0.059	0.025	5.2
32.0	164.0	1.911	0.050	0.026	5.5
32.0	164.0	1.721	0.041	0.024	6.0
45.0	160.0	1.456	0.021	0.014	8.5
45.0	160.0	1.344	0.048	0.036	0.3
60.0	158.0	1.350	0.021	0.016	8.5
60.0	158.0	2.090	0.042	0.020	5.9

TABLE 18 SULPHUR DISSOLUTION RATE EXPERIMENTAL RESULTS FOR
ALBERTA ORE #1 AT 158.0 DEG.F.

SAMPLE STANDING TIME	SAMPLE TEMPERATURE	WEIGHTS		SULPHUR DISSOLVED	
		GMS.	GMS.	GMS. S/GM. SOLN.	PERCENTAGE ERROR
0.0	156.0	4.616	0.001	0.000	107.6
1.0	154.0	1.796	0.015	0.008	10.7
2.0	154.0	2.670	0.045	0.017	5.7
3.0	155.0	2.896	0.061	0.021	5.1
4.0	155.0	3.601	0.082	0.023	4.7
5.0	156.0	3.488	0.070	0.022	4.7

TABLE 11. SULPHUR DISSOLUTION RATE AT 150°-160° F. IN LIVE FLUID
ALBERTA ORE #5 AT 150.0 DEG. F.

SAMPLE STIRRING TIME	SAMPLE TEMPERATURE DEG.F.	WEIGHTS		SULPHUR DISSOLVED PERCENTAGE	
		SOLUTION GMS.	SULPHUR GMS.	GMS. S/GM. SOLN.	
8.0	156.0	4.047	0.095	0.023	4.5
16.0	157.0	4.047	0.095	0.023	4.5
16.0	157.0	4.047	0.095	0.023	4.5
16.0	158.0	4.047	0.095	0.023	4.5
32.0	159.0	1.913	0.042	0.022	5.9
45.0	158.0	3.487	0.081	0.023	4.7
45.0	158.0	3.248	0.085	0.025	4.6
60.0	158.0	3.774	0.097	0.026	4.5

TABLE 10 SULPHUR DISSOLUTION RATE EXPERIMENTAL RESULTS FOR
ALBERTA ORE #5 AT 158.0 DEG.F.

SAMPLE STIRRING TIME MINS	SAMPLE TEMPERATURE DEG.F.	WEIGHTS		GMS. S/GM. SOLN.	SULPHUR DISSOLVED PERCENTAGE
		SOLUTION GMS.	SULPHUR GMS.		
1.0	173.0	2.147	0.051	0.024	5.5
1.0	173.0	2.722	0.069	0.025	4.9
2.0	174.0	2.953	0.083	0.028	4.7
2.0	174.0	2.800	0.088	0.031	5.1
4.0	174.0	1.254	0.024	0.019	7.9
4.0	174.0	2.220	0.057	0.026	5.3
8.0	176.0	1.173	0.028	0.024	7.3
8.0	176.0	1.408	0.031	0.022	6.9

TABLE 2. SULPHUR DISSOLUTION RATE EXPERIMENTAL RESULTS FOR
ALBERTA ORE #5 AT 179.0 DEG.F.

SAMPLE SYMBOL	SAMPLE TEMPERATURE DEG.F.	WEIGHTS		VOLUME OF SOLVENT	
		SOLUTION	SULPHUR	GMS. S/GM. SOLN.	CCS.
MINS		GMS.	GMS.		
14.0	179.0	1.179	0.010	0.008	5.3
16.0	179.0	1.031	0.057	0.051	5.3
30.0	179.0	1.171	0.035	0.031	5.3
32.0	179.0	1.021	0.014	0.013	5.3
45.0	179.0	1.127	0.033	0.029	6.7
45.0	179.0	1.047	0.043	0.037	5.3
60.0	179.0	0.750	0.008	0.011	16.9
60.0	179.0	0.889	0.012	0.013	12.6

TABLE 20 SULPHUR DISSOLUTION RATE EXPERIMENTAL RESULTS FOR ALBERTA ORE #5 AT 179.0 DEG.F.

SAMPLE STIRTING TIME
 SAMPLE TEMPERATURE
 WEIGHTS
 SULPHUR DISSOLVED
 ERROR

MIN.	DEG.F.	GMS.	GMS.	S/GM. SOLN.	
1.0	174.0	4.806	0.109	0.023	4.3
1.0	174.0	4.806	0.109	0.023	4.3
2.0	173.0	4.806	0.109	0.023	4.3
2.0	173.0	3.123	0.066	0.021	5.0
4.0	175.0	4.530	0.138	0.031	4.1
5.0	175.0	4.530	0.138	0.031	4.1
8.0	176.0	5.189	0.174	0.033	4.0
8.0	176.0	1.795	0.048	0.027	5.6

TABLE 11. SULPHUR DISSOLUTION RATE IN SULPHURIC ACID
 ALBERTA ORE #5 AT 179.0 DEG.F.

SAMPLE TIME	SAMPLE TEMPERATURE DEG.F.	WEIGHTS		SULPHUR DISSOLVED	
		SOLUTION GMS.	SOLPHUR GMS.	GMS. S/CM. SOLN.	PERCENT ERROR
16.0	178.0	4.273	0.137	0.032	4.1
18.0	178.0	4.289	0.137	0.032	4.1
32.0	179.0	4.009	0.133	0.033	4.2
32.0	178.0	4.008	0.133	0.033	4.1
45.0	179.0	3.149	0.101	0.032	4.4
45.0	179.0	3.156	0.101	0.032	4.4
45.0	179.0	3.060	0.100	0.032	4.1
45.0	178.0	3.102	0.099	0.031	4.1

PREPARED BY: S. J. B. 10/10/50
ALBERTA OPE #5 AT 170.0 DEG.F.

slurry solid component	wt solids gm.	wt solvent gm.	wt % solids	remarks
20% wt S artificial ore	225	1425	13.7	this slurry was used in all tests on the synthetic ore.
ore #1	225	1425	13.7	test at 161°F \pm 3
ore #5	130	1425	8.4	test at 156°F \pm 2
	141	1425	9.0	test at 176°F \pm 3
	225	1425	13.7	test at 176°F \pm 3

Table 22. Dissolution experiments-slurry components.

Impeller size	Tank diameter	Slurry solids content wt %	Shaft speed R.P.M.	Motor Horse Power	
				6 Straight	6 Pitched
				Blades	Blades
3"	8"	0	1005	.0287	.0191
			1175	.0364	.0233
		13.0	1005	.0263	.0183
			1170	.0401	.0278
		17.9	1005	.0287	.0199
			1170	.0427	.0343
3"	11½"	9.2	1080	.0343	.0206
			1175	.0466	.0289

Table 47. Comparison of power consumption by different impeller types at selected shaft speeds.

artificial ore sulphur content : 20% wt.
weight of ore used : 125 gms.
quantity of solvent used : 1000 ml. at room temperature

Table 48. Ore slurry conditions prior to hot water wash.

APPARATUS DETAILS

TANK DIAMETER	8.1875	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	0.7500	INS.
BAFFLE THICKNESS	0.1250	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	8.3750	INS.
IMPELLER DIAMETER	2.5000	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	3.9375	INS.
IMPELLER TYPE	TUBESHAFT WITH 6 45 DEG. PITCHED BLADES	
BLADE WIDTH	0.5000	INS.
BLADE THICKNESS	0.0625	INS.
BLADE LENGTH	1.0625	INS.
SLURRY CONCENTRATION WT. PERCENT SOLIDS ON FREE BASIS	0.0	
INCLUDING SULPHUR	0.0	
SULPHUR CONTENT OF ORE	0.0	
SLURRY TEMPERATURE	76.0	DEG.F.

APPARATUS PARAMETERS

IMPELLER/TANK DIAMETER RATIO	0.366
LIQUID DEPTH/TANK DIAMETER RATIO	1.023

TABLE 23 MIXING POWER REQUIREMENTS FOR
0.0 % WT. SOLIDS KEROSENE-ORE
SLURRY AT 76.0 DEG.F.

MEASURED SLURRY WEIGHT PERCENTAGE VOLUMES PERCENTAGE POWER PERCENTAGE

LBS.

0.12	374.0	0.001	1.8	979518.	4.2	2.25	14.9
0.13	465.0	0.002	1.9	1217849.	4.2	1.75	15.4
0.17	567.0	0.004	1.6	1484991.	4.2	1.96	14.1
0.20	715.0	0.007	2.0	1872608.	4.2	1.60	15.7
0.21	750.0	0.008	1.7	1964273.	4.2	1.57	14.3
0.25	842.0	0.012	1.9	2150037.	4.2	1.61	15.2
0.28	925.0	0.015	1.8	2422604.	4.2	1.55	15.0
0.27	900.0	0.013	1.8	2514271.	4.2	1.37	14.7
0.31	1005.0	0.019	1.8	2632127.	4.2	1.50	14.8
0.31	1000.0	0.021	1.7	2828595.	4.2	1.30	14.6
0.32	1175.0	0.023	1.7	3177502.	4.2	1.11	14.4

TABLE 23 MIXING POWER REQUIREMENTS FOR

3.0% Z KT. SOLIDS KEROSENE-OIL

SLURRY AT 76.0 DEG.F.

APPARATUS DETAILS

TANK DIAMETER	1.1875	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	0.7500	INS.
BAFFLE THICKNESS	.1250	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	8.3750	INS.
IMPELLER DIAMETER	2.0625	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	3.9375	INS.
IMPELLER TYPE	TURBINE WITH 4 STRAIGHT BLADES	
BLADE WIDTH	0.3750	INS.
BLADE THICKNESS	0.0625	INS.
BLADE LENGTH	1.0625	INS.
SLURRY CONCENTRATION		
WT. PERCENT SOLIDS S FREE BASIS	0.0	
INCLUDING SULPHUR	0.0	
SULPHUR CONTENT OF ORE	0.0	
SLURRY TEMPERATURE	76.0	DEG.F.

APPARATUS PARAMETERS

IMPELLER/TANK DIAMETER RATIO	.186
LIQUID DEPTH/TANK DIAMETER RATIO	1.023

TABLE 24 MIXING POWER REQUIRED FOR
0.0 % WT. SOLIDS KEROSENE-ORE
SLURRY AT 76.0 DEG.F.

MEASURED TORQUE	SHAFT R.P.M.	HOVER POWER	PERCENTAGE ERROR	PSYCHOLIDS NUMBER	PERCENTAGE ERROR	POWER NUMBER	PERCENTAGE ERROR
0.09	374.0	0.000	1.8	979518.	4.2	0.45	14.9
0.10	466.0	0.001	1.7	1220468.	4.2	0.58	14.4
0.22	565.2	0.025	1.6	1179193.	4.2	2.37	14.1
0.25	657.0	0.009	7.7	1720703.	4.2	2.48	21.3
0.24	750.0	0.010	1.9	1964273.	4.2	1.79	15.5
0.35	835.0	0.018	5.6	2180842.	4.2	2.44	19.5
0.36	895.0	0.020	1.8	2344033.	4.2	2.20	15.0
0.38	925.0	0.022	1.8	2422604.	4.2	2.21	15.0
0.42	925.0	0.025	4.8	2422604.	4.2	2.51	18.3
0.44	1005.0	0.029	1.8	2632127.	4.2	2.25	14.8
0.45	1095.0	0.032	4.5	2841650.	4.2	1.90	17.7
0.42	1155.0	0.031	1.7	3024983.	4.2	1.61	14.5
0.47	1175.0	0.036	1.7	3077362.	4.2	1.78	14.4

L65.

TABLE 24. MIXING POWER REQUIREMENTS FOR
0.0 % WT. SOLIDS KEROSENE-ORE
MIXTURE AT 70.0 °C.

APPARATUS DETAILS

TANK DIAMETER	8.1875	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	0.7500	INS.
BAFFLE THICKNESS	0.1250	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	9.0000	INS.
IMPELLER DIAMETER	3.0000	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	3.9375	INS.
IMPELLER TYPE	TURBINE WITH 6 STRAIGHT BLADES	
BLADE WIDTH	0.3750	INS.
BLADE THICKNESS	0.0625	INS.
BLADE LENGTH	1.0625	INS.
SLURRY CONCENTRATION WT. PERCENT SOLIDS S FREE BASIS	14.0	
INCLUDING SULPHUR	17.9	
SULPHUR CONTENT OF ORE	25.7	
SLURRY TEMPERATURE	79.0	DEG.F.

APPARATUS PARAMETERS

IMPELLER/TANK DIAMETER RATIO	0.366
LIQUID DEPTH/TANK DIAMETER RATIO	1.099

TABLE 25 MIXING POWER REQUIREMENTS FOR
17.9 % WT. SOLIDS KEROSENE-ORE
SLURRY AT 79.0 DEG.F.

MEASURED TORQUE LBS.	SHAFT R.P.M.	POWER H.P.	CONCENTR. % SOLIDS	WYFOLD WATER	PERCENTAGE WATER	POWER H.P.	PERCENTAGE WATER
0.22	643.0	0.008	2.0	1830589.	4.2	2.10	16.1
0.28	750.0	0.012	1.9	2135213.	4.2	2.17	15.5
0.41	525.0	0.005	1.3	2233424.	4.2	2.30	15.0
0.43	1005.0	0.029	1.8	2361185.	4.2	2.07	14.8
0.47	1080.0	0.034	1.7	3074707.	4.2	1.94	14.5
0.53	1170.0	0.043	1.7	3330932.	4.2	1.95	14.4

TABLE 25 MIXING POWER REQUIREMENTS FOR
17.9 % WT. SOLIDS KEROSENE-OPF
SLURRY AT 79.0 DEG.F.

APPARATUS DETAILS

TANK DIAMETER	8.1875	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	8.7500	INS.
BAFFLE THICKNESS	0.1250	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	9.0000	INS.
IMPELLER DIAMETER	3.0000	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	3.9375	INS.
IMPELLER TYPE	TUBINE WITH 6 45 DEG. PITCHED BLADES	
BLADE WIDTH	0.5000	INS.
BLADE THICKNESS	0.0625	INS.
BLADE LENGTH	1.0625	INS.
SLURRY CONCENTRATION WT. PERCENT SOLIDS S FREE BASIS	14.0	
INCLUDING SULPHUR	17.9	
SULPHUR CONTENT OF ORE	25.7	
SLURRY TEMPERATURE	79.0	DEG. F.

APPARATUS PARAMETERS

IMPELLER/TANK DIAMETER RATIO	0.366
LIQUID DEPTH/TANK DIAMETER RATIO	1.099

TABLE 26 MIXING POWER REQUIREMENTS FOR
17.9 % WT. SOLIDS KEROSENE-ORE
SLURRY AT 79.0 DEG. F.

MEASURED TORQUE	SHAFT R.P.M.	POW- ER	PERCENTAGE FEED	SYNCHROS NUMBER	PERCENTAGE ERROR	POWER NUMBER	PERCENTAGE ERROR
0.14	567.0	0.003	1.6	1614220.	4.2	1.25	14.1
0.20	745.0	0.003	1.9	2120973.	4.2	1.36	15.6
0.25	925.0	0.015	1.8	2633429.	4.2	1.42	15.0
0.32	1005.0	0.027	1.8	2641135.	4.2	1.44	14.8
0.34	1070.0	0.025	1.7	3046333.	4.2	1.37	14.6
0.44	1170.0	0.034	1.7	3337935.	4.2	1.57	14.4

TABLE 26 MIXING POWER REQUIREMENTS FOR
17.9 % WT. SOLING KEROSENE-OIL
SLURRY AT 70.2 DEG. E.

APPARATUS DETAILS

336

TANK DIAMETER	3.1375	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	0.7500	INS.
BAFFLE THICKNESS	0.1250	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	8.7500	INS.
IMPELLER DIAMETER	3.0000	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	3.9375	INS.
IMPELLER TYPE	TUBESHAFT WITH 6 45 DEG. PITCHED BLADES	
BLADE WIDTH	1.5000	INS.
BLADE THICKNESS	0.0625	INS.
BLADE LENGTH	1.0625	INS.
SLURRY CONCENTRATION WT. PERCENT SOLIDS S FREE BASIS	10.0	
INCLUDING SULPHUR	13.0	
SULPHUR CONTENT OF ORE	33.0	
SLURRY TEMPERATURE	76.0	DEG.F.

APPARATUS PARAMETERS

IMPELLER/TANK DIAMETER RATIO	0.366
LIQUID DEPTH/TANK DIAMETER RATIO	1.069

TABLE 27 MIXING POWER REQUIREMENTS FOR
13.0 % WT. SOLIDS KEROSENE-ORE
SLURRY AT 76.0 DEG.F.

MEASURED TORQUE	SHAFT R.P.M.	HORNT POWER	PERCENTAGE ERROR	REYNOLDS NUMBER	PERCENTAGE ERROR	POWER NUMBER	PERCENTAGE ERROR
0.09	181.0	0.000	2.4	503196.	4.2	1.81	17.6
0.11	374.0	0.001	1.8	1039752.	4.2	1.27	14.9
0.16	567.0	0.004	1.6	1576309.	4.2	1.48	14.1
0.20	745.0	0.007	1.9	211155.	4.2	1.28	15.5
0.30	925.0	0.016	1.8	2571581.	4.2	1.53	15.0
0.31	1005.0	0.018	1.8	2792989.	4.2	1.35	14.8
0.32	1070.0	0.020	1.7	2974694.	4.2	1.24	14.6
0.33	1120.0	0.022	1.7	3113699.	4.2	1.18	14.5
0.36	1152.0	0.025	1.7	3197101.	4.2	1.26	14.3
0.38	1170.0	0.028	1.7	3252703.	4.2	1.30	14.4

TABLE 27 MIXING POWER REQUIREMENTS FOR
13.0% 2 WT. SOLIDS KEROSENE-ORE
SLURRY AT 76.0° C.

APPARATUS DETAILS

TANK DIAMETER	8.1875	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	0.7500	INS.
BAFFLE THICKNESS	0.1250	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	8.7500	INS.
IMPELLER DIAMETER	3.0000	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	3.9375	INS.
IMPELLER TYPE	TURBINE WITH 6 STRAIGHT BLADES	
BLADE WIDTH	0.3750	INS.
BLADE THICKNESS	0.0625	INS.
BLADE LENGTH	1.0625	INS.
SLURRY CONCENTRATION		
WT. PERCENT SOLIDS S FREE BASIS	10.0	
INCLUDING SULPHUR	13.0	
SULPHUR CONTENT OF ORE	25.6	
SLURRY TEMPERATURE	76.0	DEG.F.

APPARATUS PARAMETERS

IMPELLER/TANK DIAMETER RATIO	0.366
LIQUID DEPTH/TANK DIAMETER RATIO	1.069

TABLE 28 MIXING POWER REQUIREMENTS FOR
13.0 % WT. SOLIDS KEROSENE-OIL
SLURRY AT 76.0 DEG.F.

MEASURED TORQUE LBS.	SHAFT R.P.M.	HOSE POWER	PERCENTAGE EFFICIENCY	REYNOLDS NUMBER	PERCENTAGE ERROR	POWER H.P.	PERCENTAGE ERROR
0.12	372.0	0.001	1.8	1034193.	4.2	0.86	14.9
0.19	568.0	0.004	1.6	1579090.	4.2	1.66	14.1
0.26	745.0	0.006	1.5	2071165.	4.2	1.71	15.6
0.39	925.0	0.021	1.8	2571581.	4.2	2.01	15.0
0.40	960.0	0.023	1.8	2668884.	4.2	1.93	14.9
0.43	1005.0	0.026	1.8	2793989.	4.2	1.94	14.8
0.43	1025.0	0.027	1.7	2849590.	4.2	1.87	14.7
0.44	1075.0	0.029	1.7	2988594.	4.2	1.75	14.6
0.45	1080.0	0.030	1.7	3002495.	4.2	1.78	14.6
0.51	1175.0	0.040	1.7	32665.	4.2	1.85	14.4

TABLE 28. MIXING POWER REQUIREMENTS FOR
13.0 % WT. SOLIDS KEROSENE-OIL
SLURRY AT 76.0 DEG.F.

TANK DIAMETER	9.1275	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	0.7500	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	0.1250	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	3.9275	INS.
IMPELLER TYPE	TURBINE WITH 6 45 DEG. DITCHED BLADES	
BLADE WIDTH	0.5000	INS.
BLADE THICKNESS	0.0625	INS.
BLADE LENGTH	1.0625	INS.
SLURRY CONCENTRATION WT. PERCENT SOLIDS		
FREE BASIS	17.0	
INCLUDING SULPHUR	21.6	
SULPHUR CONTENT OF ORE	25.6	
SLURRY TEMPERATURE	80.0	DEG.F.
APPARATUS PARAMETERS		
LIQUID DEPTH/TANK DIAMETER RATIO	1.115	

TABLE 20. MIXING POWER REQUIREMENTS FOR
21.6 % WT. SOLIDS KETOSENE-ORE
SLURRY AT 80.0 DEG.F.

APPARATUS DATA

TANK DATA		
NO. OF BAFFLES	4	
BAFFLE WIDTH	0.7500	INS.
BAFFLE THICKNESS	0.1250	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	0.1250	INS.
IMPELLER DATA		
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	3.0075	INS.
IMPELLER TYPE	45 DEG. PITCHED BLADES	
IMPELLER DIAMETER	1.0000	INS.
BLADE THICKNESS	0.0625	INS.
BLADE LENGTH	1.0625	INS.
SLURRY CONCENTRATION WT. PERCENT SOLIDS S FREE BASIS	17.0	
INCLUDING SULPHUR	21.6	
SULPHUR CONTENT OF SRF	25.6	
SLURRY TEMPERATURE	73.0	DEG.F.

APPARATUS PARAMETERS

IMPELLER/TANK DIAMETER RATIO	0.2500
LIQUID DEPTH/TANK DIAMETER RATIO	1.115

TABLE 20. MIXING POWER REQUIREMENTS FOR
21.6 % WT. SOLIDS KEROSENE-ORF
SLURRY AT 73.0 DEG.F.

HANDED - 2017 - 2018
 100% - 100%
 100% - 100%

0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.20	745.0	0.008	2.6	2150017.	4.2	1.33	18.7		
0.30	1070.0	0.022	2.2	3102164.	4.2	1.29	16.8		
0.42	1170.0	0.032	2.1	3392085.	4.2	1.46	16.4		

21.6 2 WT. SOLIDS KEROSENE-DEP
 SUPPLY AT 73.0 DEG.F.

APPARATUS DETAILS

TANK DIAMETER	3.0000	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	1.0000	INS.
BAFFLE THICKNESS	0.0625	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	12.1250	INS.
IMPELLER DIAMETER	3.0000	INS.
DISTANCE OF IMPELLER FROM		
BOTTOM OF TANK	1.0000	INS.
IMPELLER TYPE	45 DEG. PITCHED BLADES	
BLADE WIDTH	0.5000	INS.
BLADE THICKNESS	0.0625	INS.
BLADE LENGTH	1.0625	INS.
SLURRY CONCENTRATION		
WT. PERCENT SOLIDS		
S FREE BASIS	7.0	
SULPHUR CONTENT OF ORE	25.6	
SLURRY TEMPERATURE	71.0	DEG.F.

APPARATUS PARAMETERS

LIQUID DEPTH/TANK DIAMETER RATIO 1.000

TABLE 21. MIXING POWER REQUIREMENTS FOR
9.2 WT. SOLIDS KEROSENE-ORE
SLURRY AT 71.0 DEG.F.

TABLE 30. MIXING POWER REQUIREMENTS FOR 0.2 MFT. SUPPLY AT 70°C. (continued)

0.09	275.0	0.000	4.9	751.094.	4.3	0.80	30.3
0.13	567.0	0.002	3.0	1549618.	4.7	0.94	30.9
0.17	859.0	0.004	2.1	2526495.	4.2	1.41	17.5
0.22	1020.0	0.021	2.2	2040750.	4.2	1.24	16.7
0.26	1176.0	0.041	2.3	1711111.	4.0	1.00	15.0

TABLE 31. MIXING POWER REQUIREMENTS FOR 0.2 MFT. SUPPLY AT 70°C.

0.09	275.0	0.000	4.9	751.094.	4.3	0.80	30.3
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APPARATUS DETAILS

TANK DIAMETER	12.0000	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	1.0000	INS.
BAFFLE THICKNESS	0.1250	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	12.1250	INS.
IMPELLER DIAMETER	4.0000	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	2.0275	INS.
IMPELLER TYPE	IM- WITH STRAIGHT BLADES	
BLADE WIDE	0.3750	INS.
BLADE THICKNESS	0.0625	INS.
BLADE LENGTH	1.0625	INS.
SLURRY CONCENTRATION WT. PERCENT SOLIDS	9.2	
INCLUDING SULPHUR	9.2	
SULPHUR CONTENT OF OPE	25.6	
SLURRY TEMPERATURE	71.0	DEG.F.

APPARATUS PARAMETERS

IMPELLER/TANK DIAMETER RATIO	0.333
LIQUID DEPT./TANK DIAMETER RATIO	1.060

TABLE 20. MIXING TIMES REQUIRED FOR
9.2 % WT. SOLIDS KEROSENE-OPE
SLURRY AT 71.0 DEG.F.

DESIGN DATA

TANK DIAMETER	48.000	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	1.0000	INS.
BAFFLE THICKNESS	0.1250	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	12.1250	INS.
IMPELLER DIAMETER	48.000	INS.
IMPELLER TYPE	45 DEG. PITCHED BLADES	
BOTTOM OF TANK	4.0000	INS.
BLADE WIDTH	0.5625	INS.
BLADE THICKNESS	0.0039	INS.
BLADE LENGTH	1.5000	INS.
SLURRY CONCENTRATION		
WT. PERCENT SOLIDS		
S. FREE BASIS	7.2	
INCLUDING SULPHUR	9.2	
SULPHUR CONTENT OF ORE	25.6	
SLURRY TEMPERATURE	72.0	DEG.F.

DESIGN CALCULATIONS

LIQUID DEPTH/TANK DIAMETER RATIO 1.060

TABLE 23. MIXING POWER REQUIREMENTS FOR
9.2% WT. SOLIDS KEROSENE-ORE
SLURRY AT 72.0 DEG.F.

APARATUS DETAILS

TANK DIAMETER	11.4375	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	1.0000	INS.
BAFFLE THICKNESS	0.1250	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	12.5625	INS.
IMPELLER DIAMETER	4.0000	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	4.0000	INS.
IMPELLER TYPE	TOWARD WITH 2 45 DEG. PITCHED BLADES	
BLADE WIDTH	1.0625	INS.
BLADE THICKNESS	0.0938	INS.
BLADE LENGTH	1.0000	INS.
SLURRY CONCENTRATION		
WT. PERCENT SOLIDS S FREE BASIS	17.9	
INCLUDING SULPHUR	17.9	
SULPHUR CONTENT IN OIL	15.4	
SLURRY TEMPERATURE	78.0	DEG.F.

APARATUS PARAMETERS

IMPELLER/TANK DIAMETER RATIO	0.350
LIQUID DEPTH/TANK DIAMETER RATIO	1.094

TABLE 34 MIXING POWER REQUIREMENTS FOR
17.9 % WT. SOLIDS KEROSENE-ORF
SLURRY AT 78.0 DEG.F.

MEASURED TORQUE LBS.	SHAFT R.P.M.	HORSE POWER	PERCENTAGE ERROR	REVOLUTIONS NUMBER	PERCENTAGE ERROR	POWERS NUMBER	PERCENTAGE ERROR
0.36	563.0	0.012	3.0	2875135.	3.2	1.15	17.6
0.57	745.0	0.029	2.6	3771083.	3.2	1.21	15.6
0.82	920.0	0.054	2.4	4656908.	3.2	1.20	14.4
1.05	1060.0	0.082	3.3	5365568.	3.2	1.19	14.9
1.22	1185.0	0.103	3.0	5749216.	3.2	1.22	14.5

TABLE 34 MIXING POWER REQUIREMENTS FOR

17.5% WT. SOLIDS KEROSENE-
SLURRY AT 75.0 DEG.F.

APPARATUS DETAILS

TANK DIAMETER	11.4375	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	1.0000	INS.
BAFFLE THICKNESS	0.1250	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	12.5625	INS.
IMPELLER DIAMETER	4.0000	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	4.0000	INS.
IMPELLER TYPE	TURBINE WITH 6 45 DEG. PITCHED BLADES	
BLADE WIDTH	0.5625	INS.
BLADE THICKNESS	0.0938	INS.
BLADE LENGTH	1.5000	INS.
SLURRY CONCENTRATION WT. PERCENT SOLIDS S FREE BASIS	14.0	
INCLUDING SULPHUR	17.9	
SULPHUR CONTENT OF OIL	25.0	
SLURRY TEMPERATURE	76.0	DEG.F.

APPARATUS PARAMETERS

IMPELLER/TANK DIAMETER RATIO	0.35
LIQUID DEPTH/TANK DIAMETER RATIO	1.098

TABLE 35 MIXING POWER REQUIREMENTS FOR
17.9 % WT. SOLIDS KEROSENE-OIL
SLURRY AT 76.0 DEG.F.

MEASURED TORQUE	SHAFT R.P.M.	HORSE POWER	PERCENTAGE ERROR	REYNOLDS NUMBER	PERCENTAGE ERROR	POWER NUMBER	PERCENTAGE ERROR
0.35	567.0	0.012	3.0	2870074.	3.2	1.16	17.6
0.59	745.0	0.030	2.6	3771083.	3.2	1.26	15.6
0.84	925.0	0.055	2.3	4682217.	3.2	1.22	14.4
1.11	1080.0	0.088	3.2	5466809.	3.2	1.22	14.8
1.25	1175.0	0.109	3.0	5947683.	3.2	1.17	14.3

TABLE 35 MIXING POWER REQUIREMENTS FOR
17.3% WT. SOLIDS KEROSENE-DE
SLURRY AT 75.0 DEG.F.

APPARATUS DETAILS

TANK DIAMETER	11.4375	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	1.0000	INS.
BAFFLE THICKNESS	0.1250	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	12.2500	INS.
IMPELLER DIAMETER	4.0000	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	4.0000	INS.
IMPELLER TYPE	TURBINE WITH 6 45 DEG. PITCHED BLADES	
BLADE WIDTH	0.5625	INS.
BLADE THICKNESS	0.0938	INS.
BLADE LENGTH	1.5000	INS.
SLURRY CONCENTRATION WT. PERCENT SOLIDS S FREE BASIS	10.0	
INCLUDING SULPHUR	13.0	
SULPHUR CONTENT OF ORE	25.6	
SLURRY TEMPERATURE	72.0	DEG.F.

APPARATUS PARAMETERS

IMPELLER/TANK DIAMETER RATIO	0.350
LIQUID DEPTH/TANK DIAMETER RATIO	1.071

TABLE 36 MIXING POWER REQUIREMENTS FOR
13.0 % WT. SOLIDS KEPOSENE-ORE
SLURRY AT 72.0 DEG.F.

MEASURED TORQUE LBS.	SHAFT R.P.M.	POWER POWER	PERCENTAGE ERROR	SYMBOLS NUMBER	PERCENTAGE ERROR	POWER NUMBER	PERCENTAGE ERROR
0.39	567.0	0.014	3.0	2803099.	3.2	1.36	17.6
0.59	745.0	0.030	2.6	3683082.	3.2	1.29	15.6
0.81	925.0	0.054	2.3	4572952.	3.2	1.20	14.4
1.07	1080.0	0.085	3.2	5339237.	3.2	1.20	14.8
1.21	1175.0	0.105	3.0	5808891.	3.2	1.15	14.3

TABLE 36 MIXING POWER REQUIREMENTS FOR

13.0 % WT. SOLIDS KEROSENE-OIL

SLURRY AT 72.0 DEG.F.

APPARATUS DETAILS

TANK DIAMETER	11.4375	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	1.0000	INS.
BAFFLE THICKNESS	0.1250	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	12.2500	INS.
IMPELLER DIAMETER	3.0000	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	3.9375	INS.
IMPELLER TYPE	TURNING WITHIN 45 DEG. PITCHED BLADES	
BLADE WIDTH	1.0000	INS.
BLADE THICKNESS	0.0625	INS.
BLADE LENGTH	1.0625	INS.
SLURRY CONCENTRATION		
WT. PERCENT SOLIDS S FREE BASIS	10.0	
INCLUDING SULPHUR	13.0	
SULPHUR CONTENT OF ORE	25.	
SLURRY TEMPERATURE	73.0	DEG.F.

APPARATUS PARAMETERS

IMPELLER/TANK DIAMETER RATIO	0.262
LIQUID DEPTH/TANK DIAMETER RATIO	1.071

TABLE 37 MIXING TIME DATA FOR
13.0 % WT. SOLIDS KEROSENE-OIL
SLURRY AT 73.0 DEG.F.

MEASURED TORQUE	SHAFT R.P.M.	HORSE POWER	PERCENTAGE ERROR	REYNOLDS NUMBER	PERCENTAGE ERROR	POWER NUMBER	PERCENTAGE ERROR
0.13	567.0	0.003	3.0	1576743.	4.2	1.11	20.8
0.19	745.0	0.007	2.0	71731.	4.2	1.29	18.7
0.26	925.0	0.014	2.3	2572290.	4.2	1.32	17.5
0.35	1085.0	0.026	2.2	1673323.	4.2	1.43	16.7
0.41	1175.0	0.032	2.1	3267504.	4.2	1.46	16.4

TABLE 37 MIXING POWER REQUIREMENTS FOR
13.0% WT. SOLIDS KEROSENE-CRE
SLURRY AT 73.0°F.

183.

NO. OF BAFFLES	4	
BAFFLE WIDTH	1.0000	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SURFICIAL LIQUID DEPTH	12.7500	INS.
IMPELLER DIAMETER	4.0000	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	4.0000	INS.
IMPELLER TYPE	THERMIX WITH 6 45 DEG. PITCHED BLADES	
BLADE THICKNESS	0.0020	INS.
BLADE LENGTH	1.8000	INS.
SLURRY CONCENTRATION WT. PERCENT SOLIDS S. FREE BASIS	17.0	
INCLUDING SULPHUR	21.6	
SULPHUR CONTENT OF ORE	5.	
SLURRY TEMPERATURE	82.0	DEG.F.

LIQUID DEPT H/TANK DIAMETER RATIO 1.115

TABLE 28. MIXING POWER REQUIREMENTS FOR
21.6 WT. SOLIDS KEROSENE-
SLURRY AT 82.0 DEG.F.

TANK DIAMETER	15.8750	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	1.2500	INS.
BAFFLE HALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	16.4375	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	4.1250	INS.
IMPELLER TYPE	45 DEG. PITCHED BLADES	
IMPELLER DIAMETER	0.5625	INS.
BLADE THICKNESS	0.0038	INS.
SLURRY CONCENTRATION WT. PERCENT SOLIDS S FREE BASIS	7.1	
SLURRY VISCOSITY	25.6	
SLURRY TEMPERATURE	78.0	DEG.F.

LIQUID DEPTH/TANK DIAMETER RATIO 1.035

TABLE 39 MIXING POWER REQUIREMENTS FOR
0.4 % WT. SOLIDS KEROSENE-ORE
SLURRY AT 78.0 DEG.F.

APPARATUS DETAILS

NO. OF BAFFLES	4	
BAFFLE WIDTH	1.2500	INS.
BAFFLE THICKNESS	0.1250	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	16.6875	INS.
IMPELLER DIAMETER	4.0000	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	4.1250	INS.
	45 DEG. PITCHED BLADES	
	1.5000	INS.
BLADE THICKNESS	0.0025	INS.
BLADE LENGTH	1.5000	INS.
CONCENTRATION		
WT. PERCENT SOLIDS ON FREE BASIS	9.8	
INCLUDING SULPHUR	12.7	
HEIGHT OF L.F.	25.6	
IMPELLER/TANK DIAMETER RATIO	0.252	
LIQUID DEPTH/TANK DIAMETER RATIO	1.051	

TABLE 40. MIXING POWER REQUIREMENTS FOR
12.7 WT. SOLIDS REPRESENTATIVE
SLURRY AT 73.0 DEG.F.

MEASURED VALUES	SHAFT DIA. IN.	HORSE POWER	PERCENTAGE ERROR	REYNOLDS NUMBER	PERCENTAGE ERROR	POWER NUMBER	PERCENTAGE ERROR
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1884

0.80	915.0	0.052	2.4	4517533.	3.2	1.21	14.5
1.11	1060.0	0.037	3.2	5233434.	3.2	1.29	14.9
1.21	1200.0	0.028	4.0	6000000.	4.0	1.35	15.5

TABLE 1. EFFECT OF SHAFT DIAMETER ON
12.7 KW. SOLIDS KEROSENE-CUT
3000 RPM TEST RESULTS

APPENDIX 41

TANK DATA

NO. OF BAFFLES	4	
BAFFLE WIDTH	1.2500	INS.
BAFFLE THICKNESS	0.1253	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	17.1250	INS.
IMPELLER DIAMETER	1.2500	INS.

DISTANCE OF IMPELLER FROM

BOTTOM OF TANK	4.1250	INS.
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IMPELLER TYPE.....TURBINE WITH 6
45 DEG. PITCHED BLADES

BLADE WIDTH	0.5000	INS.
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BLADE THICKNESS	0.0938	INS.
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BLADE LENGTH	1.2500	INS.
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SLURRY CONCENTRATION

WT. PERCENT SOLIDS S FREE BASIS	15.0
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INCLUDING SULPHUR	19.2
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SULPHUR CONTENT OF ORE	25.4
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SLURRY TEMPERATURE	80.0	DEG.F.
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APPARATUS CHARACTERISTICS

IMPELLER/TANK DIAMETER RATIO	0.252
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LIQUID DEPTH/TANK DIAMETER RATIO	1.079
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TABLE 41 MIXING POWER REQUIREMENTS FOR
19.2 % WT. SOLIDS KEROSENE-ORE
SLURRY AT 80.0 DEG.F.

CATEGORY TIME DATE LOCATION STATION NUMBER PROPORTION NUMBER PERCENT

0.54	745.0	0.027	2.6	3793792.	3.2	1.11	15.6
0.78	915.0	0.050	2.4	4659491.	3.2	1.13	14.5
1.16	1060.0	0.090	3.2	5297981.	3.2	1.20	14.3
1.29	1140.0	0.109	3.0	5305263.	3.2	1.26	14.4

TABLE 41 MIXING POWER REQUIREMENTS FOR
 SLOPE AT 80.0 DEG.

NO. OF BAFFLES	4	
BAFFLE WIDTH	1.2500	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	17.2500	INS.
IMPELLER DIAMETER	6.0000	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	4.1250	INS.
IMPELLER TYPE	45 DEG. TITLED BLADES	
BLADE THICKNESS	0.0034	INS.
BLADE LENGTH		
WT. PERCENT SOLIDS S. FREE BASIS	15.0	
SLURRY TEMPERATURE	100.0	DEG.F.
APPARATUS PARAMETERS		
LIQUID DEPTH/TANK DIAMETER RATIO	1.097	

TABLE 42 MIXING POWER REQUIREMENTS FOR
15.2 WT. SOLIDS KEROSENE-OIL
SLURRY AT 100.0 DEG.F.

MEASURED	SHAFT	HOSE	PERCENTAGE	REYNOLDS	PERCENTAGE	POWER	PERCENTAGE
0.76	915.0	0.040	2.4	5541582.	3.2	1.11	14.5
0.99	1005.0	0.065	2.3	6036658.	3.2	1.11	14.0
1.07	1060.0	0.082	3.2	6410753.	3.2	1.21	14.9
1.10	1140.0	0.099	3.1	6904207.	3.2	1.17	14.5

10.2 3 RT. SOLIDS PER GPM-ORE
SLURRY AT 100.0 DEG.

MIXER DETAILS

NO. OF BASFLES	4	
BASFLR WIDTH	1.2500	INS.
BASFLR THICKNESS	0.1000	INS.
BASFLR WALL CLEARANCE	0.0625	INS.
SUPRFRICIAL LIQUID DPTH	17.4375	INS.
DISTANCE OF IMPELLR FRM BOTTON OF TANK	4.1250	INS.
IMPELLR TYPE	TIPRING WITH 6 45 DEG. PITCHED BLADES	
BLADE THICKNESS	0.0250	INS.
SLURRY CONCENTRATION		
WT. PERCENT SOLIDS S FREE BASIS	15.0	
INCLUDING SULPHUR	16.2	
CONTENT OF OCE	25.4	
SLURRY TEMPERATURE	122.0	DEG.F.
LIQUID DPTH/TANK DIAMETER RATIO	1.093	

TABLE 43. MIXING POWER REQUIREMENTS FOR
10.2 % WT. SOLIDS KEROSENE-ORE
SLURRY AT 122.0 DEG.F.

MEASURED SHEAR	SHAFT SPEED	HORSE POWER	PERCENTAGE	REYNOLDS	PERCENTAGE	POWER	PERCENTAGE
0.75	915.0	0.049	2.4	6642607.	3.2	1.14	14.5
0.89	1005.0	0.065	2.3	7295931.	3.2	1.14	14.0
1.00	1140.0	0.089	3.1	8276037.	3.2	1.13	14.5

TABLE 43 MIXING POWER REQUIREMENTS FOR

51 PPM

APPARATUS DETAILS

TANK DIAMETER	15.8750	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	1.2500	INS.
BAFFLE THICKNESS	0.1283	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	17.6250	INS.
IMPELLER DIAMETER	4.0000	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	4.1250	INS.
IMPELLER TYPE	TURBINE WITH 6 45 DEG. PITCHED BLADES	
BLADE WIDTH	1.0000	INS.
BLADE THICKNESS	0.0038	INS.
BLADE LENGTH	1.5000	INS.
SLURRY CONCENTRATION WT. PERCENT SOLIDS S FREE BASIS	19.2	
INCLUDING SULPHUR	19.2	
SULPHUR CONTENT OF ORE	3.0	
SLURRY TEMPERATURE	142.0	DEG.F.

APPARATUS PARAMETERS

IMPELLER/TANK DIAMETER RATIO	0.252
LIQUID DEPTH/TANK DIAMETER RATIO	1.111

TABLE 44 MIXING POWER REQUIREMENTS FOR
19.2 % WT. SOLIDS KEROSENE-ORE
SLURRY AT 142.0 DEG.F.

MEASURED TORQUE LBS.	SHAFT R.P.M.	HOPSE	PERCENTAGE	REYNOLDS	PERCENTAGE	POWER	PERCENTAGE
0.77	915.0	0.051	2.4	7879228.	3.2	1.18	14.5
0.88	1005.0	0.065	2.3	8654241.	3.2	1.14	14.0
1.06	1060.0	0.083	3.2	9127851.	3.2	1.25	14.0
1.14	1140.0	0.097	3.1	9816751.	3.2	1.17	14.5

TABLE 44 MIXING POWER REQUIREMENTS FOR
19.2 % WT. SOLIDS KEROSENE-ORE
SLURRY AT 142.0 DEG.F.

APPARATUS DETAILS

TANK DIAMETER	15.8750	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	1.2500	INS.
BAFFLE THICKNESS	0.1283	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	17.6250	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	4.1250	INS.
IMPELLER TYPE	45 DEG. PITCHED BLADES	
BLADE WIDTH	0.5625	INS.
BLADE THICKNESS	0.0938	INS.
BLADE LENGTH	1.5000	INS.
SLURRY CONCENTRATION WT. PERCENT SOLIDS S FREE BASIS	19.2	
INCLUDING SULPHUR	19.2	
SULPHUR CONTENT OF ORE	25.4	
SLURRY TEMPERATURE	144.0	DEG.F.

APPARATUS PARAMETERS

IMPELLER/TANK DIAMETER RATIO	0.252
LIQUID DEPTH/TANK DIAMETER RATIO	1.117

TABLE 45 MIXING POWER REQUIREMENTS FOR
19.2 % WT. SOLIDS KEROSENE-ORE
SLURRY AT 144.0 DEG.F.

APPARATUS DETAILS

TANK DIAMETER	15.8750	INS.
NO. OF BAFFLES	4	
BAFFLE WIDTH	1.2500	INS.
BAFFLE THICKNESS	0.1283	INS.
BAFFLE WALL CLEARANCE	0.0625	INS.
SUPERFICIAL LIQUID DEPTH	16.5625	INS.
IMPELLER DIAMETER	4.0000	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF TANK	4.1250	INS.
IMPELLER TYPE	TURBINE WITH 6 45 DEG. PITCHED BLADES	
BLADE WIDTH	0.5625	INS.
BLADE THICKNESS	0.0938	INS.
BLADE LENGTH	1.5000	INS.
SLURRY CONCENTRATION WT. PERCENT SOLIDS S FREE BASIS	16.7	
INCLUDING SULPHUR	21.2	
SULPHUR CONTENT OF ORE	25.4	
SLURRY TEMPERATURE	78.0	DEG.F.

APPARATUS PARAMETERS

IMPELLER/TANK DIAMETER RATIO	0.252
LIQUID DEPTH/TANK DIAMETER RATIO	1.043

TABLE 46 MIXING POWER REQUIREMENTS FOR
21.2 % WT. SOLIDS KEROSENE-ORE
SLURRY AT 78.0 DEG.F.

Impeller size	Tank diameter	Slurry solids content wt %	Shaft speed R.P.M.	Motor Horse Power	
				6 Straight	6 Pitched
				Blades	Blades
3"	8"	0	1005	.0287	.0191
			1175	.0364	.0233
		13.0	1005	.0263	.0183
			1170	.0401	.0278
		17.9	1005	.0287	.0199
			1170	.0427	.0343
3"	11½"	9.2	1080	.0343	.0206
			1175	.0466	.0289

Table 47. Comparison of power consumption by different impeller types at selected shaft speeds.

artificial ore sulphur content : 20% wt.
weight of ore used : 125 gms.
quantity of solvent used : 1000 ml. at room temperature

Table 48. Ore slurry conditions prior to hot water wash.

Water to Solvent Ratio by volume	Agitation Time seconds	Temperature °F	Solvent retained on solids					
			ml.	volume % of solvent inventory		volume % of solids in slurry		
				measured	maximum	measured	maximum	maximum
0.214	0	158	19.0	30.3	1.9	2.9	24.7	36.4
	10	158	0.0	8.3	0.0	0.8	0.0	13.5
	30	158	0.0	9.3	0.0	0.9	0.0	14.9
0.345	0	156	13.0	24.8	1.3	2.4	18.8	32.7
	10	156	17.0	28.8	1.6	2.8	23.3	36.1
	30	156	17.0	28.8	1.6	2.8	23.3	36.1
0.366	0	157	53.0	64.5	5.1	6.2	49.4	56.6
	15	157	26.0	37.5	2.5	3.6	32.5	43.3
	45	157	24.0	35.5	2.3	3.4	30.8	41.8
0.561	0	154	25.0	32.8	2.4	3.2	28.7	36.5
	15	154	33.0	40.8	3.2	3.9	34.7	41.7

Table 49. Gangue washing experimental results.

Water to kerosene Ratio by volume	Water kerosene interfacial condition after stirring
0.21	no scum present
0.35	some scum present
0.37	some scum present
0.40	some scum present
0.50	thick scum formed
0.56	scum and emulsion together
0.59	emulsion formed but will collapse on mild agitation
0.61	emulsion formed but will collapse on mild agitation
0.69	emulsion formed but will collapse on mild agitation
0.75	stable emulsion formed

note: critical water to kerosene ratio for no emulsion formation
is about 0.6.

Table 50. Emulsion build up for kerosene water ore system.

time	liquid suspension interfacial height			
minutes	inches			
0	11.47	9.56	7.96	7.24
2.5	11.18	9.32	-	-
3.0	-	-	7.77	-
4.5	-	-	-	7.06
5.0	10.75	-	-	-
7.0	-	8.85	-	-
7.5	10.39	-	-	6.83
8.0	-	-	7.36	-
10.0	10.04	-	-	-
10.5	-	8.49	-	-
12.0	-	-	6.94	-
12.5	9.68	-	-	-
13.5	-	-	-	6.29
15.0	9.32	7.96	-	-
18.0	-	-	6.35	5.88
20.0	8.55	7.42	-	-
24.0	-	6.95	5.76	5.40
25.0	7.90	-	-	-
temperature °F	134	135	135	126
suspension solids content wt %	12.95	15.25	18.00	19.55
settling rate ft/hr	0.736	0.548	0.475	0.425

Note: No caustic soda added to suspension

Table 51. Sedimentation rate experimental results.

time minutes	liquid suspension interfacial height		
	inches		
0	11.47	9.37	7.66
2.0	11.10	-	-
3.0	-	-	7.47
4.5	10.68	-	-
5.0	-	8.78	-
7.5	10.18	-	-
8.5	-	-	6.82
10.0	-	8.13	-
12.0	9.44	-	-
13.0	-	-	6.23
14.0	-	7.59	-
18.0	8.43	-	5.64
20.0	-	6.76	-
24.0	-	6.23	4.86
temperature °F	128	128	128
suspension solids content wt %	12.95	15.50	18.50
settling rate ft/hr	0.857	0.654	0.631

Note: caustic soda added to the suspension

Table 51. Sedimentation rate experimental results continued.

initial slurry concentration wt % solids	settling rate, u_c ft/hr	initial liquid concentration, U lbs H ₂ O/lb solid	final liquid concentration, V lbs H ₂ O/lb solid	settling parameter $\frac{U-V}{u_c}$
12.95	0.736	6.73	0.428	8.56
15.25	0.548	5.56	0.428	9.36
18.00	0.475	4.56	0.428	8.70
19.55	0.425	4.12	0.428	8.65
12.95	0.857	6.75	0.428	7.30
15.50	0.654	5.48	0.428	7.74
18.50	0.631	4.41	0.428	6.32

Table 52. Alberta ore tailings settling parameter derivation.

Average time for settling	22.5 secs \pm 2.5
Initial slurry solids content	5.9 wt.%
Initial suspension height	10.74 ins.
Final suspension height	1.09 ins.
Calculated settling rate	128 ft/hr \pm 19
Temperature	74°F
Calculated settling rate for 0.1mm dia. particle using Stokes Law	129 ft/hr.

Table 53. Sulphur sedimentation test results.

Pressure drop lb_f/in^2		3.9	4.6
Time seconds	Filtrate Volume ml.		
0	0	0	
10	-	20.0	
15	5.5	-	
30	-	50.0	
40	25.0	70.0	
50	-	85.0	
60	65.0	95.0	
80	-	125.0	
90	105.0	140.0	
100	-	155.0	
110	-	170.0	
120	150.0	180.0	
130	-	195.0	
140	-	210.0	
150	-	220.0	
slope of curve		0.72	0.70

slurry concentration : 32.4 wt % solids

filter diameter : 2.65 ins.

Table 54. Sulphur filtration results.

SULPHUR RECOVERY UNIT

INPUT INFORMATION REQUIRED
FOR PLANT DESIGN

PHYSICAL PROPERTY DATA

TEMPERATURE DEG.F.	SPECIFIC GRAVITY SOLVENT	WATER	VISCOSITY SOLVENT	CPS WATER
32.0	0.810	1.000	2.62	1.56
50.0	0.800	1.000	2.22	1.28
60.0	0.795	1.000	2.03	1.11
70.0	0.790	0.997	1.85	1.01
74.0	0.787	0.997	1.80	0.98
80.0	0.785	0.995	1.71	0.93
90.0	0.781	0.992	1.59	0.82
94.0	0.780	0.991	1.50	0.79
100.0	0.778	0.990	1.42	0.74
110.0	0.773	0.989	1.30	0.66
120.0	0.770	0.985	1.20	0.60
130.0	0.763	0.982	1.12	0.55
135.0	0.762	0.981	1.10	0.52
140.0	0.760	0.980	1.05	0.50
150.0	0.756	0.979	0.97	0.46
155.0	0.753	0.977	0.93	0.43
160.0	0.751	0.975	0.89	0.42
165.0	0.750	0.974	0.86	0.40
170.0	0.748	0.972	0.84	0.38
175.0	0.745	0.970	0.79	0.36
180.0	0.742	0.969	0.77	0.35
185.0	0.740	0.967	0.73	0.34
190.0	0.739	0.965	0.72	0.32
200.0	0.734	0.962	0.66	0.29
230.0	0.720	0.953	0.54	0.23

SPECIFIC GRAVITY OF SULPHUR 2.00

SPECIFIC GRAVITY OF ORE INSOLUBLES 1.65

VISCOSITY OF AIR AT AMBIENT CONDITIONS 0.018 CPS

TABLE 55 SULPHUR RECOVERY UNIT
SPECIFIC GRAVITY & VISCOSITY DATA

TEMPERATURE DEG.F.	SPECIFIC BTU/LB.DEG.F.	HEAT
-----------------------	---------------------------	------

SOLVENT	RATE
---------	------

32.0	0.45500	1.00803
50.0	0.46500	1.00194
68.0	0.47500	0.99947
86.0	0.48600	0.99866
104.0	0.49800	0.99869
122.0	0.50800	0.99919
140.0	0.51800	1.00007
158.0	0.52800	1.00131
176.0	0.53800	1.00294
194.0	0.54900	1.00502
212.0	0.56000	1.00763
230.0	0.57000	1.00900
250.0	0.58000	1.01100

SPECIFIC HEAT OF ORE INSOLUBLES	0.22400
---------------------------------	---------

TABLE 56	SULPHUR RECOVERY UNIT SPECIFIC HEAT DATA
----------	---

SEDIMENTATION RATE OF ORE INSOLUBLES	0.000152 FT/SEC
---	-----------------

SEDIMENTATION RATE OF SULPHUR CRYSTALS	0.000152 FT/SEC
---	-----------------

TABLE 57	SULPHUR RECOVERY UNIT MISCELLANEOUS DATA
----------	---

TEMPERATURE DEG.F.	SOLUBILITY GMS. S/GM. SOLUTION
-----------------------	-----------------------------------

32.0	0.0
50.0	0.0
60.0	0.0006
70.0	0.0015
74.0	0.0020
80.0	0.0025
90.0	0.0043
94.0	0.0050
100.0	0.0063
110.0	0.0085
120.0	0.0110
130.0	0.0140
135.0	0.0150
140.0	0.0167
150.0	0.0202
155.0	0.0222
160.0	0.0243
165.0	0.0265
170.0	0.0292
175.0	0.0320
180.0	0.0350
185.0	0.0383
190.0	0.0419
200.0	0.0500

TABLE 58 SULPHUR RECOVERY UNIT
SULPHUR SOLUBILITY IN KEROSENE

MECHANICAL DESIGN PARAMETERS

SHELL I.D. INS.

TUBE COUNT
ONE PASS

8.00	36.
10.00	62.
12.00	109.
14.25	127.
15.25	170.
17.25	239.
19.25	301.
21.25	361.
23.25	442.
25.00	532.
27.00	637.
29.00	721.
31.00	847.
33.00	974.
35.00	1122.
37.00	1240.
39.00	1377.

DATA FOR 3/4 IN. O.D. TUBES
ON 15/16 IN. TRIANGULAR PITCH

TABLE 59 SULPHUR RECOVERY UNIT TUBE SHEET LAYOUT

NOMINAL PIPE SIZE

INTERNAL DIAMETER

INS.

INS.

1.0	1.049
1.5	1.610
2.0	2.067
3.0	3.068
4.0	4.026
6.0	6.065
8.0	7.981
10.0	10.020
12.0	12.000
16.0	16.000
20.0	19.250
24.0	23.250

TABLE 60

SULPHUR RECOVERY UNIT
STANDARD STEEL PIPE DIMENSIONS

VISCOSITY	K (PR) ^{1/3}
CPS	BTU/HR(SQ.FT.)(DEG.F./FT.)

0.1	0.197
0.2	0.183
0.3	0.172
0.4	0.165
0.5	0.165
0.6	0.165
0.7	0.165
0.8	0.164
0.9	0.164
1.0	0.211
1.1	0.211
1.2	0.222
1.3	0.228
1.4	0.235
1.5	0.238
1.6	0.241
1.7	0.250
1.8	0.255
1.9	0.258
2.0	0.263
2.1	0.268
2.2	0.275
2.3	0.281
2.4	0.284
2.5	0.288
2.6	0.295
2.7	0.299
2.8	0.299
2.9	0.295
3.0	0.291
3.1	0.289
3.2	0.283
3.3	0.280
3.4	0.277
3.5	0.274
3.6	0.271
3.7	0.272
3.8	0.269
3.9	0.267
4.0	0.267

TABLE 61 . . . SULPHUR RECOVERY UNIT
K (PR)^{1/3} VALUES FOR SOLVENT

REYNOLDS NUMBER	JH TUBE SIDE	FACTOR SHELL SIDE
--------------------	-----------------	----------------------

100.	0.0	5.0
100.	1.3	5.0
300.	1.9	6.9
500.	2.2	11.8
800.	2.6	14.0
1000.	2.8	14.0
1300.	3.1	18.0
1500.	3.2	20.2
1800.	3.4	22.2
2000.	3.5	23.0
2200.	4.0	24.0
2400.	5.0	24.0
2600.	5.8	27.0
2800.	6.8	27.0
3000.	7.5	29.0
3200.	8.5	30.0
3400.	9.2	31.0
3600.	10.5	32.0
3800.	11.5	34.0
4000.	12.0	35.0
4500.	14.0	36.0
5000.	16.0	37.0
5500.	18.0	40.0
6000.	21.0	42.0
6500.	22.0	43.0
7000.	24.0	45.0
8000.	28.0	49.0
9000.	33.0	52.0
10000.	36.0	55.0
15000.	52.0	60.0
20000.	68.0	65.0
30000.	96.0	70.0
40000.	128.0	75.0
50000.	160.0	77.0
60000.	176.0	78.0
80000.	216.0	79.0
100000.	256.0	80.0
200000.	450.0	85.0
300000.	670.0	88.0
500000.	900.0	90.0
600000.	1100.0	90.0

TABLE 62 SULPHUR RECOVERY UNIT
HEAT TRANSFER CURVE DATA

REYNOLDS NUMBER	COMMERCIAL PIPE	FRICTION FACTORS EXCHANGER TUBES	EXCHANGER SHELL
100.	0.161	0.004900	0.00620
300.	0.0550	0.001250	0.00410
400.	0.0340	0.001000	0.00370
800.	0.0210	0.000640	0.00340
1000.	0.0170	0.000500	0.00330
1300.	0.0140	0.000430	0.00310
1500.	0.0120	0.000400	0.00300
1800.	0.0094	0.000430	0.00290
2000.	0.0140	0.000420	0.00285
2200.	0.0130	0.000410	0.00280
2400.	0.0125	0.000400	0.00275
2600.	0.0120	0.000390	0.00270
2800.	0.0115	0.000385	0.00265
3000.	0.0110	0.000380	0.00262
3200.	0.0105	0.000370	0.00260
3400.	0.0104	0.000365	0.00258
3600.	0.0103	0.000360	0.00255
3800.	0.0102	0.000355	0.00252
4000.	0.0100	0.000350	0.00251
4500.	0.0095	0.000340	0.00250
5000.	0.0092	0.000330	0.00242
5500.	0.0090	0.000320	0.00235
6000.	0.0087	0.000310	0.00230
6500.	0.0085	0.000305	0.00228
7000.	0.0083	0.000300	0.00225
8000.	0.0081	0.000290	0.00220
9000.	0.0079	0.000280	0.00215
10000.	0.0077	0.000270	0.00210
15000.	0.0069	0.000245	0.00195
20000.	0.0063	0.000220	0.00185
25000.	0.0060	0.000200	0.00175
40000.	0.0055	0.000190	0.00160
50000.	0.0052	0.000178	0.00155
60000.	0.0051	0.000170	0.00150
80000.	0.0049	0.000157	0.00142
100000.	0.0045	0.000149	0.00138
200000.	0.0041	0.000125	0.00120
300000.	0.0039	0.000115	0.00110
500000.	0.0036	0.000102	0.00100
600000.	0.0035	0.000098	0.00098
800000.	0.0034	0.000092	0.00092
1000000.	0.0033	0.000088	0.00088

TABLE 63. SULPHUR RECOVERY UNIT
REYNOLDS NUMBER VS FRICTION FACTOR DATA

REYNOLDS NUMBER

POWER NUMBER

5.	10.1
10.	5.8
20.	4.0
30.	3.4
40.	2.9
50.	2.7
75.	2.3
100.	2.0
200.	1.6
300.	1.5
500.	1.4
750.	1.3
1000.	1.3
5000.	1.3
10000.	1.3
50000.	1.3
100000.	1.3
500000.	1.3
1000000.	1.3
900000000.	1.3

TABLE 64

SULPHUR RECOVERY UNIT
REYNOLDS NUMBER VS POWER NUMBER DATA

THICKENER DIAMETER FT	RAKE MOTOR HORSE POWER
10.	0.25
12.	0.50
16.	0.75
26.	1.00
40.	1.50
50.	2.00
75.	3.00
150.	5.00
200.	7.50

TABLE 65 SULPHUR RECOVERY UNIT
THICKENER RAKE MOTOR DATA

BELT CAPACITY S. TONS/HR	BELT WIDTH INS	BELT SPEED FT/MIN	HORSE POWER PER 10FT. RISE	HORSE POWER PER 100FT. HORIZONTAL LENGTH
--------------------------------	----------------------	-------------------------	-------------------------------	---

44.0	16.0	100.0	0.44	0.36
88.0	16.0	200.0	0.90	1.12
132.0	16.0	300.0	1.36	1.68

TABLE 66 SULPHUR RECOVERY UNIT
CONVEYOR DETAILS

PUMP EFFICIENCY 0.70

MOTOR EFFICIENCY 0.88

LINE ELEVATION 2.0 FT

TABLE 67 SULPHUR RECOVERY UNIT
MISCELLANEOUS DATA

ADDITIONAL EQUIPMENT COST DATA

CAPACITY	PRICE
USGPM	DOLLARS

1.5	165.
3.0	231.
12.0	311.
24.0	610.
51.0	784.
71.0	846.
105.0	1042.
137.0	2057.
195.0	2171.
490.0	3470.

TABLE 68 SULPHUR RECOVERY UNIT
SCREW PUMP COST DATA

CAPACITY	PRICE
CFM	DOLLARS

31.0	1600.
67.0	1800.
92.0	2050.
80.0	2120.
73.0	2180.
75.0	2190.
90.0	2700.
100.0	2800.
200.0	3800.
300.0	4400.
500.0	5500.

TABLE 69 SULPHUR RECOVERY UNIT
VACUUM PUMP COST DATA

LENGTH	PRICE
FT	DOLLARS
10.0	1000.
20.0	1500.
40.0	2500.
70.0	3700.
100.0	4800.
150.0	6200.
200.0	7500.
300.0	12000.
400.0	18000.
600.0	28000.
1000.0	48000.

TABLE 70 SULPHUR RECOVERY UNIT
CONVEYOR BELT COST DATA

SULPHUR RECOVERY UNIT

PLANT DESIGN VARIABLES

DESIGN VARIABLES

FEED	WT. FRACTION
------	--------------

TYPICAL ORE COMPOSITION

SULPHUR	0.40
CLAYS ETC.	0.70
WATER	0.090

TAILINGS

SOLVENT CONTENT	0.135
BONDED WATER CONTENT	0.090

SULPHUR PRODUCT

SOLVENT CONTENT	0.005
WATER CONTENT	0.0

SULPHUR PRODUCTION RATE	200.0	S. TONS/DAY
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TABLE 71	SULPHUR RECOVERY UNIT	INPUT DATA
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PROCESS TEMPERATURES

	DEG. F.
ORE FEED	60.0
SOLVENT MAKE UP	60.0
COOLING WATER	38.0
CRYSTALLISER TEMPERATURE	73.5
ESTIMATED EXTRACTION TEMPERATURE	180.0

TABLE 71 SULPHUR RECOVERY UNIT INPUT DATA

OTHER PARAMETERS

	WT. FRACTION	
SLURRY SOLIDS CONTENT	0.150	
THICKENED TAILINGS SOLIDS CONTENT	0.650	
SOLVENT DISENGAGING FROM TAILINGS DURING THICKENING - FRACTION OF SOLVENT INITIALLY RETAINED ON SOLIDS	0.900	
SULPHUR SLURRY FILTER FEED, WATER CONTENT	0.450	
SOLVENT OCCLUDED ON SULPHUR AFTER SETTLING PRIOR TO FILTERING	0.157	SULPHUR
SOLVENT REMAINING ON SULPHUR AFTER FILTERING PRIOR TO WASHING WITH WATER	0.078	SULPHUR
WASH WATER FOR SULPHUR PRODUCT	1.000	SULPHUR
	VOL. FRACTION	
COOLING WATER FOR RICH SOLVENT	0.340	SOLVENT
WASH WATER FOR SOLVENT SLURRY EX MIXERS	0.210	SOLVENT

TABLE 71 SULPHUR RECOVERY UNIT INPUT DATA

MEAN FLUID RESIDENCE TIME	20.0 MINS.
NUMBER OF MIXERS	3.
LIQUID DEPTH/TANK DIAMETER RATIO	1.
IMPELLER DIAMETER/TANK DIAMETER RATIO	0.4
ERROR FACTOR IN POWER NUMBER	1.1
NUMBER OF BAFFLES	4.
BAFFLE WIDTH/TANK DIAMETER RATIO	0.2
NUMBER OF TURBINE BLADES	6.
BLADE WIDTH/IMPELLER DIAMETER RATIO	0.2
IMPELLER HEIGHT FROM TANK BASE TO IMPELLER DIAMETER RATIO	1.
REYNOLDS NUMBER	2000000.

TABLE 72 SULPHUR RECOVERY UNIT
MIXER DESIGN DATA

MINIMUM DESIGN SOLIDS PARTICLE SIZE REQUIRED IN UNDERFLOW OR OVERFLOW	1.0 mm. DIA.
MINIMUM DESIGN LIQUID DROPLET SIZE REQUIRED IN UNDERFLOW OR OVERFLOW	1.0 mm. DIA.
SETTLER DESIGN SAFETY FACTOR	1.25
MINIMUM RESIDENCE TIME	30.0 SECS
SETTLING TIME TO DESIRED UNDERFLOW SOLIDS CONTENT OF TAILINGS	140.0 SECS
SETTLING TIME TO DESIRED UNDERFLOW SOLIDS CONTENT OF FILTER FEED	70.0 SECS

TABLE 73 SULPHUR RECOVERY UNIT
THICKENER DESIGN VARIABLES

TUBE LENGTH	20.0 FT.
TUBE INSIDE DIAMETER	0.620 INS.
TUBE OUTSIDE DIAMETER	0.750 INS.
TUBE PITCH	0.9375 INS.
OUTSIDE SURFACE AREA/LIN. FT.	0.1963 SQ. INS./FT.
INTERNAL FLOW AREA	0.302 SQ. INS.
NUMBER OF TUBE PASSES	1.
ESTIMATED OVERALL HEAT TRANSFER COEFFICIENT	30.0 BTU/(HR)(SQ.FT)(DEG.F)
DIRT FACTOR REQUIRED	0.0050 (HR)(SQ.FT)(DEG.F)/BTU

TABLE 74 SULPHUR RECOVERY UNIT
HEAT EXCHANGER DESIGN DATA

FRACTION OF DRUM SUBMERGED	0.30
FRACTION OF DRUM FOR AIR SUCTION	0.10
DRUM ROTATION SPEED	0.50 R.P.M.
PRESSURE DROP ACROSS FILTER	5.00 PSI
FILTER MEDIA RESISTANCE	60.00 (HR/FT) ²
FILTER MEDIA AIR SUCTION RESISTANCE	60.00 (HR/FT) ²
NUMBER OF FILTER UNITS	1.

TABLE 75 SULPHUR RECOVERY UNIT
ROTARY VACUUM FILTER DESIGN PARAMETERS

OTHER PARAMETERS

SOLVENT HOLD-UP
STORAGE CAPACITY 30.0 DAYS

OVERDESIGN FACTOR FOR
STORAGE CAPACITY 0.10

MAXIMUM NUMBER OF MIXERS
OUT OF SERVICE 1. UNITS

MAXIMUM NUMBER OF HEAT
EXCHANGERS OUT OF SERVICE 1. UNITS

ALL PUMPING EQUIPMENT IS SPARED
WITH 1. EXTRA UNIT

MARSHALL-STEVENSON COST INDEX
FOR 1970 297.

TABLE 76 SULPHUR RECOVERY UNIT MISCELLANEOUS DATA.....

RAW MATERIALS AND UTILITIES

MINING COST	1.50	\$/TON ORE
ELECTRICITY	0.027	\$/KWHR
PROCESS WATER	0.200	\$/M USG
NATURAL GAS	0.555	\$/M SCF
SOLVENT MAKE-UP	0.133	\$/USG

OPERATING LABOUR

NUMBER OF ON-STREAM HOURS	8000.	HOURS/YEAR
NUMBER OF OPERATORS PER SHIFT	4.	
OPERATORS WAGE	3.75	\$/HR

TABLE 77 SULPHUR RECOVERY UNIT
PROCESSING COST DETAILS

PRODUCTION COST ITEMS

SUPERVISION	0.10	FRACTION OF OPERATING LABOUR
MAINTENANCE	0.04	FRACTION OF FIXED CAPITAL
OPERATING SUPPLIES	0.01	FRACTION OF FIXED CAPITAL
LABORATORY CHARGES	0.15	FRACTION OF OPERATING LABOUR
PLANT OVERHEAD	0.60	FRACTION OF OPERATING LABOUR, SUPERVISION AND MAINTENANCE
ADMINISTRATION COST	0.15	FRACTION OF OPERATING LABOUR, SUPERVISION AND MAINTENANCE
INTEREST RATE	0.09	% CHARGED ON TOTAL CAPITAL
FIXED COSTS	0.15	FRACTION OF DIRECT COSTS
SELLING COSTS	0.05	FRACTION OF DIRECT COSTS
RESEARCH AND DEVELOPMENT	0.02	FRACTION OF DIRECT COSTS

TABLE 78 SULPHUR RECOVERY UNIT
PROCESSING COST DETAILS

RAW MATERIALS AND UTILITIES

MINING COST	1.50	\$/TON ORE
ELECTRICITY	0.027	\$/KWHR
PROCESS WATER	0.200	\$/M USG
NATURAL GAS	0.555	\$/M SCF
SOLVENT MAKE-UP	0.133	\$/USG

OPERATING LABOUR

NUMBER OF ON-STREAM HOURS	8000.	HOURS/YEAR
NUMBER OF OPERATORS PER SHIFT	4.	
OPERATORS WAGE	3.75	\$/HR

TABLE 77 SULPHUR RECOVERY UNIT PROCESSING COST DETAILS

PRODUCTION COST ITEMS

SUPERVISION	0.10	FRACTION OF OPERATING LABOUR
MAINTENANCE	0.04	FRACTION OF FIXED CAPITAL
OPERATING SUPPLIES	0.01	FRACTION OF FIXED CAPITAL
LABORATORY CHARGES	0.15	FRACTION OF OPERATING LABOUR
PLANT OVERHEAD	0.60	FRACTION OF OPERATING LABOUR, SUPERVISION AND MAINTENANCE
ADMINISTRATION COST	0.15	FRACTION OF OPERATING LABOUR, SUPERVISION AND MAINTENANCE
INTEREST RATE	0.09	% CHARGED ON TOTAL CAPITAL
FIXED COSTS	0.15	FRACTION OF DIRECT COSTS
SELLING COSTS	0.05	FRACTION OF DIRECT COSTS
RESEARCH AND DEVELOPMENT	0.02	FRACTION OF DIRECT COSTS

TABLE 78 SULPHUR RECOVERY UNIT PROCESSING COST DETAIL

SULPHUR RECOVERY UNIT

PLANT SPECIFICATIONS

STREAM	OUT FEED	SOLVENT CYCLE	KEROSENE & OPE SLURRY	SLURRY WASH WATER	KEROSENE WATER & OPE SLURRY
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FLOWSHEET NUMBER	1	2	3	4	5
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COMPONENT	1	2	3	4	5
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SULPHUR	16683.7	882.6	17566.4	158.5	17724.9
CLAYS	45412.4	0.0	5612.5	0.0	5612.5
WATER	715.2	0.0	715.2	124957.2	132037.3
SOLVENT	0.0	455197.6	455197.6	6507.7	461705.2
TOTAL	79446.3	456080.2	538976.6	131563.4	667759.8

ALL STREAMS ARE MEASURED IN LBS/HR.

TABLE 79 SULPHUR RECOVERY UNIT MATERIAL BALANCE

STREAM	TAILINGS	RICH SOLVENT	COOLING WATER	WATER & RICH SOLVENT MIXTURE	SULPHUR & WATER SLURRY
FLWSHEET NUMBER	6	7	8	9	1
SULPHUR	175.7	17554.3	0.2	17554.2	1871.0
CLAYS	45512.5	1.1	1.2	1.2	0.0
WATER	132037.3	0.0	195971.3	195971.3	15775.8
SOLVENT	4425.3	457481.4	0.0	457481.4	2011.0
TOTAL	172244.8	474335.6	195971.3	670507.9	25557.4

ALL STREAMS ARE MEASURED IN LBS/HR.

TABLE 79 SULPHUR RECOVERY UNIT MATERIAL BALANCE CONTINUED

STREAM	LEAN SOLVENT RECYCLE	SOLVENT MAKE UP	RATE TO PLANT	RATE TO FILTER	WASH WATER EX FILTER
FLWSHEET NUMBER	11	12	13	14	15
COMPONENT					
SULPHUR	882.6	0.0	0.0	0.0	4.9
CLAYS	0.0	0.0	0.0	0.0	0.0
RATE	0.0	0.0	212427.8	15656.7	212637.2
SOLVENT	454571.0	524.1	0.0	0.0	2524.2
TOTAL	455554.1	524.1	212427.8	15656.7	21516.2

ALL STREAMS ARE MEASURED IN LBS/HR.

TABLE 79 SULPHUR RECOVERY UNIT MATERIAL BALANCE CONTINUED

STREAM	WATER TO POND	WASH WATER MAKE UP	WASH WATER RECYCLE	THICKENED TAILINGS	SULPHUR PRODUCT
FLOW SHEET PUMPS	16	17	18	19	20
COMPONENT					
SULPHUR	0.0	4.9	153.6	17.1	1666.7
CLAYS	0.0	0.0	0.0	55612.5	0.0
WATER	189842.8	22795.1	102092.1	29945.2	0.0
SOLVENT	0.0	2526.2	3981.4	442.4	83.8
TOTAL	189842.8	25326.2	106075.1	56117.1	16750.4

ALL STREAMS ARE MEASURED IN LBS/HR.

TABLE 73 FLOW SHEET RECOVERY UNIT MATERIAL BALANCE CONTINUED

STREAM	FEED TO SULPHUR THICKENER	THICKENER OVERFLOW	WATER DISPOSAL PUMP FEED
FLYDISH NUMBER	21	22	23
COMPONENT			
SULPHUR	16671.6	0.0	4.9
CLAYS	0.0	0.0	0.0
WATER	195471.7	121195.4	32442.5
SOLIDS	3411.2	1.0	3526.3
TOTAL	187494.5	121196.4	34773.6

ALL STREAMS ARE MEASURED IN LBS/HR.

SULPHUR RECOVERY 0.999WT. FRACTION OF SULPHUR IN ORE FEED

TABLE 79 SULPHUR RECOVERY UNIT MATERIAL BALANCE CONTINUED

HEAT ENTERING PLANT

HEAT LEAVING PLANT

STREAM NUMBER	STREAM DESCRIPTION	HEAT CONTENT BTU / HR	STREAM NUMBER	STREAM DESCRIPTION	HEAT CONTENT BTU / HR
1	ORE FEED	628740.8	16	WATER TO POND	7440530.0
12	SOLVENT MAKE UP	6817.5	19	THICKENED TAILINGS	6443390.0
13	COOLING WATER	1284776.0	20	SULPHUR PRODUCT	34354.0
HEAT FROM SOLVENT HEATER E-1		11784505.0			

TOTAL

13704839.0

TOTAL

13918273.0

PERCENTAGE DIFFERENCE 1.6

DATUM TEMPERATURE

32.0 DEG. F.

TABLE 6 STEAM RECOVERY UNIT HEAT BALANCE

STREAM
FLOWSHEET
NUMBERTEMPERATURE
STREAM SECTION
2

3

1	58.0		
2	73.5	152.8	77.1
3	193.7		
4	162.3		
5	183.3		
6	183.3		
7	133.3	104.8	
8	38.0		
9	73.5		
10	73.5		
11	73.5		
12	38.0		
13	38.0		
14	38.0		
15	71.1		
16	71.1		
17	71.1		
18	183.3		
19	183.3		
20	44.1		
21	73.5		
22	73.5		
23	58.4		

ALL STREAMS ARE MEASURED IN DEG. F.

TABLE 81 SULPHUR RECOVERY UNIT
PROCESS OPERATING TEMPERATURES

STREAM
FLOWSHEET
NUMBERFLUID DENSITY
STREAM SECTION
2

3

1	100.77		
2	49.13	46.89	45.60
3	50.07		
4	59.91		
5	50.92		
6	68.02		
7	46.22	48.40	
8	50.4		
9	53.25		
10	79.62		
11	49.13		
12	49.61		
13	62.40		
14	62.40		
15	62.02		
16	62.21		
17	60.62		
18	59.67		
19	82.24		
20	123.88		
21	64.51		
22	62.21		
23	61.25		

ALL STREAMS MEASURED IN LBS./CU. FT.

TABLE 82 SULPHUR RECOVERY UNIT STREAM DENSITY

STREAM FLOWSHEET NUMBER	FLUID VISCOSITIES STREAM SECTION		
	1	2	3
2	1.81	0.90	0.63
3	0.74		
4	0.41		
5	0.74		
6	0.34		
7	0.74	1.36	
8	1.46		
9	1.81		
11	1.81		
12	2.03		
13	1.46		
14	1.46		
15	1.00		
16	1.00		
17	1.00		
18	0.34		
21	0.98		
22	0.98		
23	1.14		

ALL STREAMS MEASURED IN CPS.

TABLE 83 SULPHUR RECOVERY UNIT STREAM VISCOSITIES

MEAN FLUID RESIDENCE TIME	20.0	MINS
NUMBER OF MIXERS	3.	
MIXER VOLUME	8889.6	USG
VESSEL DIAMETER	11.5	FT
VESSEL HEIGHT	11.5	FT
MOTOR R.P.M.	78.	
MOTOR HORSE POWER	7.3	
IMPELLER TYPE	TURBINE WITH 45 DEG. PITCHED BLADES	
NUMBER OF BLADES	6.	
TURBINE DIAMETER	45.5	INS.
BLADE WIDTH	4.5	INS.
DISTANCE OF IMPELLER FROM BOTTOM OF VESSEL	45.5	INS.
NUMBER OF BAFFLES	4.	
BAFFLE WIDTH	12.4	INS.

TABLE 84 SULPHUR RECOVERY UNIT
AGITATOR SPECIFICATIONS

FLOW SHEET NUMBER	VESSEL	DUTY	VOLUME USG	DIAMETER FT	HEIGHT FT	MOTOR HORSE POWER
D-1	SOLVENT STORAGE		73837.4	23.3	23.3	
D-2	SOLVENT K.O. DRUM		237.8	1.9	11.1	
S-1	HIGH SOLVENT SEPARATOR AND TAILINGS SLURRY THICKENER					
	UPPER PORTION		312532.2	133.0	3.0	
	LOWER PORTION		328739.9	133.0	3.2	5.0
S-2	LEAN SOLVENT SEPARATOR AND SULPHUR SLURRY THICKENER					
	UPPER PORTION		13441.0	23.4	3.2	
	LOWER PORTION		10107.0	23.4	3.2	1.0

TABLE 85
SULPHUR RECOVERY UNIT
PROCESS VESSEL SIZES

HEAT EXCHANGER

420

FLOWSHEET NUMBER

E-2

SERVICE

RICH SOLVENT COOLER

TOTAL HEAT DUTY

19608160.0 BTU/HR

NUMBER OF UNITS

6. PLACED IN SERIES

HEAT DUTY PER UNIT

3268026.0 BTU/HR

LOG MEAN TEMPERATURE DIFFERENCE

27.7 DEG.F.

AREA PER UNIT

4868.2 SQ.FT.

OVERALL HEAT TRANSFER
COEFFICIENT --- CLEAN

28.4 BTU/(HR)(SQ.FT)(DEG.F)

--- DIRTY

24.2 BTU/(HR)(SQ.FT)(DEG.F)

DIRT FACTOR --- REQUIRED

0.0050 (HR)(SQ.FT)(DEG.F)/BTU

--- CALCULATED

0.0061 (HR)(SQ.FT)(DEG.F)/BTU

SHELL SIDE TUBE SIDE

FLUID HANDLED

SOLVENT RECYCLE RICH SOLVENT

FLOW RATE

LBS/HR

456080.2

474835.6

TEMPERATURES

INLET

DEG.F.

73.5

183.3

OUTLET

DEG.F.

158.8

104.8

VISCOSITY

INLET

CPS

1.81

0.74

OUTLET

CPS

0.90

1.36

DENSITY

INLET

LBS/CU.FT.

49.13

46.22

OUTLET

LBS/CU.FT.

46.89

48.40

CALCULATED

PRESSURE DROP

PSI

5.5

0.7

TABLE 86

SULPHUR RECOVERY UNIT
HEAT EXCHANGER SPECIFICATIONS

TUBE LENGTH	20.0 FT.
TUBE INSIDE DIAMETER	0.620 INS.
TUBE OUTSIDE DIAMETER	0.750 INS.
TUBE PITCH	0.9375 INS.
TUBES PER UNIT	1240.
NUMBER OF TUBE PASSES	1.
SHELL INSIDE DIAMETER	37.00 INS.
BAFFLE SPACING	37.0 INS.

TABLE 87 SULPHUR RECOVERY UNIT
HEAT EXCHANGER SPECIFICATIONS

TOTAL SLURRY FEED TO FILTER UNITS	35057.4	LBS/HR
TOTAL WASH TO FILTER UNITS	16666.7	LBS/HR
TOTAL SOLID PRODUCT EX FILTER UNITS	16750.4	LBS/HR
NUMBER OF FILTER UNITS	1.	
FILTER DRUM AREA	185.3	SQ.FT/UNIT
DRUM ROTATION SPEED	0.50	R.P.M.
PRESSURE DROP ACROSS FILTER	5.00	PSI
VACUUM PUMP CAPACITY AT PUMP INLET CONDITIONS	120.3	CFM
VACUUM PUMP MOTOR SIZE	3.6	HORSE POWER

TABLE 88 SULPHUR RECOVERY UNIT
POTARY VACUUM FILTER SPECIFICATIONS

HEAT DUTY	11784505.0	BTU/HR
HEATER THERMAL EFFICIENCY	75.0	
GAS REQUIREMENT	15645.4	SCF/HR
HEATING VALUE OF GAS	913.0	BTU/SCF
AIR REQUIREMENT	163904.0	SCF/HR
PERCENTAGE STOICHIOMETRIC AIR REQUIREMENT	110.0	

TABLE 89 SULPHUR RECOVERY UNIT
 SOLVENT RECYCLE HEATER

PUMP DUTY	PUMP NUMBER	CAPACITY USGPM	MOTOR HORSE POWER
SOLVENT SLURRY CIRCULATION	1	1333.4	12.8
WATER/SOLVENT SLURRY CIRCULATION	2	1633.1	14.4
WASTE DISPOSAL	3	130.4	3.2
COOLING WATER DISPOSAL	4	432.5	3.6
FILTRATE PUMP	5	71.2	0.9
COOLING WATER FILL	6	432.5	3.6
SOLVENT SLURRY CIRCULATION	7	54.9	0.7
LEAN SOLVENT RECYCLE	8	1157.2	19.8

TABLE 90

SULPHUR RECOVERY UNIT
PUMP CAPACITY & MOTOR SIZES

BELT DUTY	BELT NUMBER	BELT RISE	BELT LENGTH	BELT CAPACITY	BELT WIDTH	BELT SPEED	MOTOR HORSE POWER	MATERIAL DENSITY
		FT	FT	S.TON/HR	INS	FT/MIN		LBS/CU.FT.
ORE FEED TO PLANT	1	34.0	25.0	39.7	16.0	90.	2.7	100.8
SULPHUR CONVEYOR	2	34.0	25.0	39.7	16.0	90.	2.7	100.8

TABLE 91
SULPHUR RECOVERY UNIT
CONVEYOR SPECIFICATIONS

STREAM FLOWSHEET NUMBER	STREAM SECTION	PIPE DIAMETER NOMINAL BORE INCHES.	FLUID VELOCITY FT/SEC	PRESSURE DROP, PER 100FT LENGTH OF LINE LBS/SQ. IN.
-------------------------------	-------------------	--	-----------------------------	--

1	1	12.0	4.7	1.24
2	2	12.0	3.4	0.10
3	3	12.0	3.5	0.10
4		8.0	14.2	3.18
5		6.0	7.1	0.14
6		6.0	10.2	1.00
7	1	12.0	3.6	0.10
8	2	12.0	3.4	0.10
9		6.0	2.3	0.11
10		6.0	10.1	1.00
11		7.0	8.2	2.45
12		12.0	4.7	1.24
13		6.0	1.7	0.10
14		6.0	1.8	0.10
15		6.0	2.8	0.11
16		6.0	2.4	0.10
17		6.0	2.3	0.10
18		6.0	2.5	0.12
19		4.0	3.3	14.28
22		8.0	2.3	0.09
23		6.0	2.1	0.08

TABLE 92

SULPHUR RECOVERY UNIT
LINE SIZES & PRESSURE DROPS

EQUIPMENT ITEM	UNIT COST	TOTAL COST
	U.S. \$	U.S. \$
D - 1	10366.	10366.
D - 2	487.	487.
S - 1	110822.	110822.
S - 2	17569.	17569.
A - 1	8271.	24814.
E - 1	34448.	34448.
E - 2	14757.	88543.
F - 1	14607.	14607.
P - 1	1632.	3263.
P - 2	1701.	3401.
P - 3	2387.	4774.
P - 4	1198.	2397.
P - 5	91.	182.
P - 6	1165.	2331.
P - 7	1803.	3606.
P - 8	1928.	3856.
P - 9	3464.	6928.
C - 1	12041.	12041.
C - 2	12041.	12041.
SUB TOTAL		53138.

TABLE 93 SULPHUR RECOVERY UNIT
ESTIMATED EQUIPMENT COSTS

EQUIPMENT ITEM	UNIT COST U.S. \$	TOTAL COST U.S. \$
SUB TOTAL		353138.
MOTOR FOR P - 1	723.	1446.
MOTOR FOR P - 2	763.	1526.
MOTOR FOR P - 3	468.	935.
MOTOR FOR P - 4	479.	958.
MOTOR FOR P - 5	404.	808.
MOTOR FOR P - 6	479.	958.
MOTOR FOR P - 7	397.	793.
MOTOR FOR P - 8	901.	1802.
MOTOR FOR P - 9	481.	481.
MOTOR FOR C - 1	454.	454.
MOTOR FOR C - 2	392.	392.
MOTOR FOR A - 1	579.	1736.
MOTOR FOR S - 1	518.	518.
MOTOR FOR S - 2	406.	406.
TOTAL		366348.

TABLE 93 SULPHUR RECOVERY UNIT
ESTIMATED EQUIPMENT COSTS

	FRACTION OF PURCHASED EQUIPMENT COSTS	COST \$	TOTAL CAPITAL INVESTED \$
DIRECT COSTS			
PURCHASED EQUIP.	100.	366348.	
PURCHASED EQUIP. INSTALLATION	52.	190501.	
INSTRUMENTATION	9.	32971.	
PIPING	44.	161193.	
ELECTRICS	11.	40298.	
BUILDINGS (INC. SERVICES)	47.	172184.	
YARD IMPROVEMENTS	10.	36635.	
SERVICES	55.	201492.	
LAND PURCHASE	6.	21981.	
TOTAL DIRECT PLANT COST			1223602.
INDIRECT COSTS			
ENGINEERING & SUPERVISION	27.	98914.	
CONSTRUCTION EXPENSE	47.	172184.	
TOTAL DIRECT AND INDIRECT PLANT COSTS			1494699.
CONTRACTORS FEES	26.	73270.	
CONTINGENCY	41.	150203.	
FIXED CAPITAL INVESTMENT			1718170.
WORKING CAPITAL	83.	304069.	
TOTAL CAPITAL INVESTMENT			2022239.

TABLE 94

SULPHUR RECOVERY UNIT
PLANT FIXED CAPITAL INVESTMENT BASED ON
DELIVERED EQUIPMENT COSTS

COST ITEM	\$	\$ 430
RAW MATERIALS	476678.	
ELECTRICITY	16601.	
COOLING WATER	40783.	
NATURAL GAS	69466.	
SOLVENT MAKE-UP	84408.	
OPERATING LABOUR	131400.	
SUPERVISION	13140.	
MAINTENANCE	68727.	
OPERATING SUPPLIES	17182.	
LABORATORY CHARGES	19710.	
DIRECT PRODUCTION COSTS		938093.
FIXED CHARGES		246162.
PLANT OVERHEADS		127960.
ADMINISTRATION COSTS	31990.	
DISTRIBUTION COSTS	82054.	
R & D CHARGES	32822.	
INTEREST CHARGES	182001.	
GENERAL EXPENSES		328867.
TOTAL PRODUCT COST		1641081.
PRODUCTION COST PER TON SULPHUR PRODUCT		24.62
MANUFACTURING COST PER TON SULPHUR PRODUCT		19.68

TABLE 95 SULPHUR RECOVERY UNIT
TOTAL PRODUCTION COSTS

ELECTRICITY	76.9	KWHR
COOLING WATER	25.5	M USG/HR
NATURAL GAS	15.6	M SCF/HR
SOLVENT MAKE-UP	79.3	USG/HP

TABLE 96 SULPHUR RECOVERY UNIT
PLANT UTILITY REQUIREMENTS

sulphur crystallisation temperature OF	cooling water ratio	tailings solids concentration wt.fraction	annual costs			plant cost \$ x 10 ⁶	production cost \$/ton	manu- facturing cost \$/ton
			water	gas	maintenance			
68.0	.36	.65	42695	65334	75563	1.889	25.19	19.93
70.0			42762	67635	72753	1.819	24.98	19.85
72.5			42927	70559	69006	1.725	24.70	19.75
75.0			43058	73586	69230	1.731	24.79	19.82
77.5			43134	76547	66642	1.666	24.61	19.76
80.0			43210	79470	64719	1.618	24.49	19.73
72.5	.30	.65	36305	63595	74823	1.871	24.96	19.75
	.32		38513	65952	73859	1.846	24.97	19.80
	.33		39616	67075	72418	1.810	24.88	19.77
	.34		40720	68236	72605	1.815	24.94	19.82
	.35		41824	69397	68820	1.720	24.64	19.70
	.36		42927	70559	69006	1.725	24.70	19.75
	.37		44031	71721	70198	1.755	24.85	19.84
	.38		45135	72883	70387	1.760	24.91	19.89
	.40		47342	75209	69752	1.744	24.95	19.95

based on 1970 construction prices.

Table 97. Plant optimisation summary.

sulphur crystallisation temperature of	cooling water ratio	tailings solids concentration wt.fraction	annual costs water	gas	annual costs maintenance	plant cost \$ x 10 ⁶	production cost \$/ton	manu- facturing cost \$/ton
71.0	.34	.65	40626	66532	74099	1.852	25.05	19.86
	.35		41727	67640	72657	1.816	24.95	19.83
	.36		42828	68749	72840	1.821	25.01	19.98
73.5	.32	.65	38572	67070	72320	1.808	24.85	19.75
	.33		39677	68224	72507	1.813	24.91	19.80
	.34*		40783*	69421*	68724*	1.718*	24.61*	19.68*
	.35		4.888	70618	69918	1.748	24.76	19.77
	.36		42994	71815	70107	1.753	24.83	19.82
73.5	.35	.65	40783	69421	68724	1.718	24.61	19.68
		.60	40783	74136	68273	1.707	24.66	19.74
		.55	40783	79705	67701	1.693	24.71	19.82
		.50	40783	86384	66956	1.674	24.77	19.90

for 1970 construction prices. optimum case shown thus *

Table 97. Plant optimisation summary continued.

APPENDIX IX

Figures

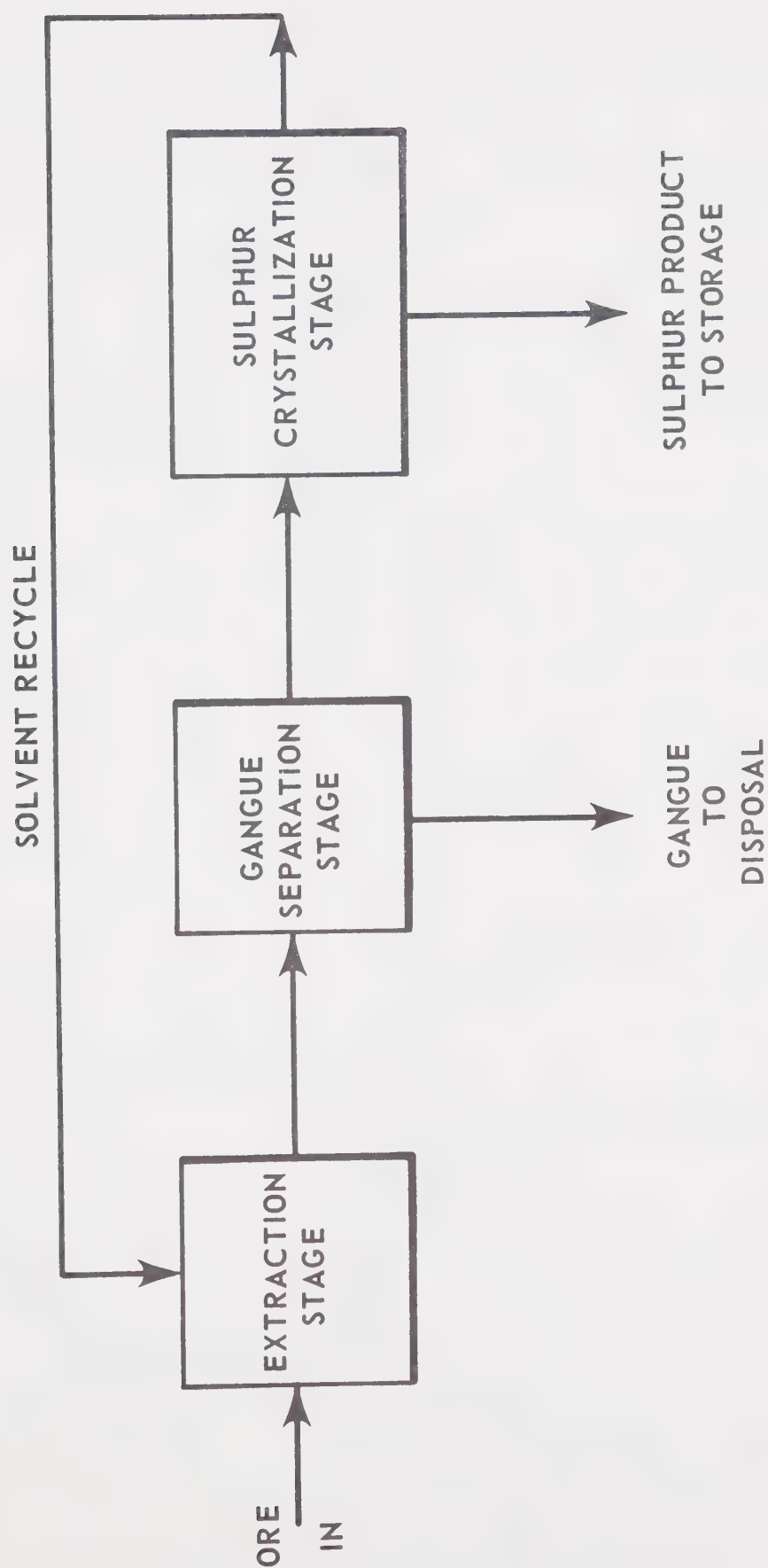


FIGURE 1: SOLVENT EXTRACTION PROCESS BLOCK DIAGRAM

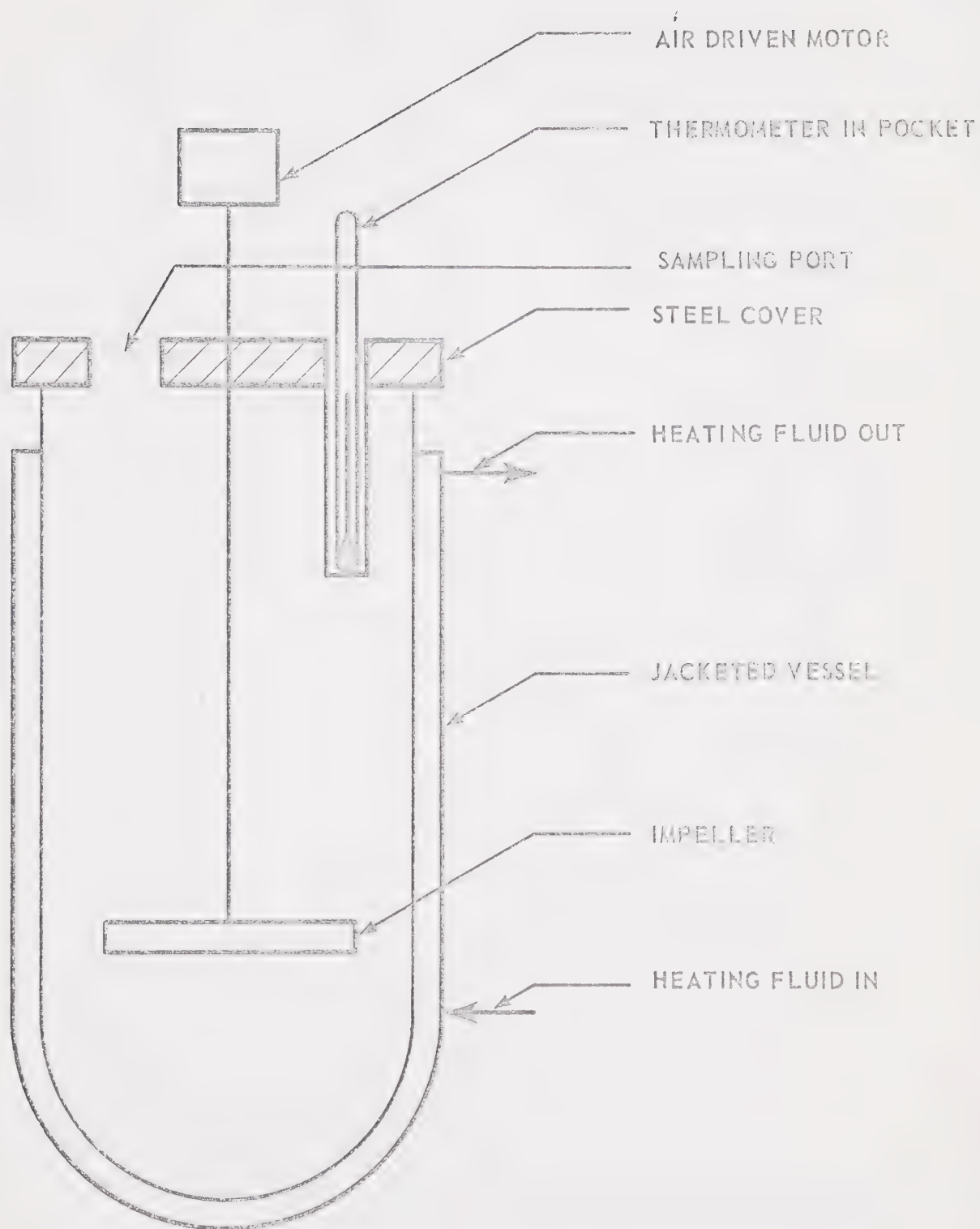


FIGURE 2: MIXING APPARATUS

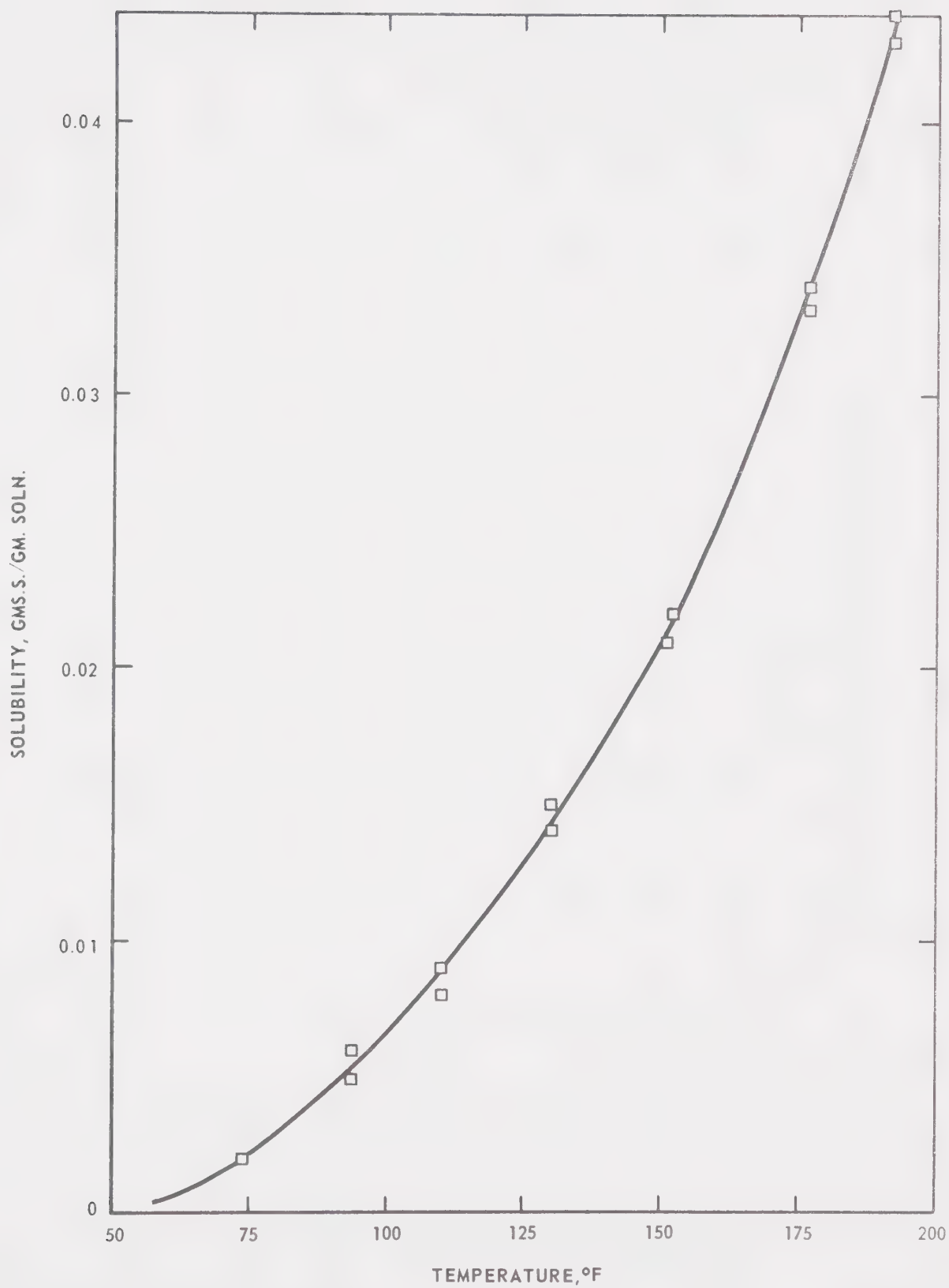


FIGURE 3: SOLUBILITY CURVE FOR SULPHUR IN KEROSENE

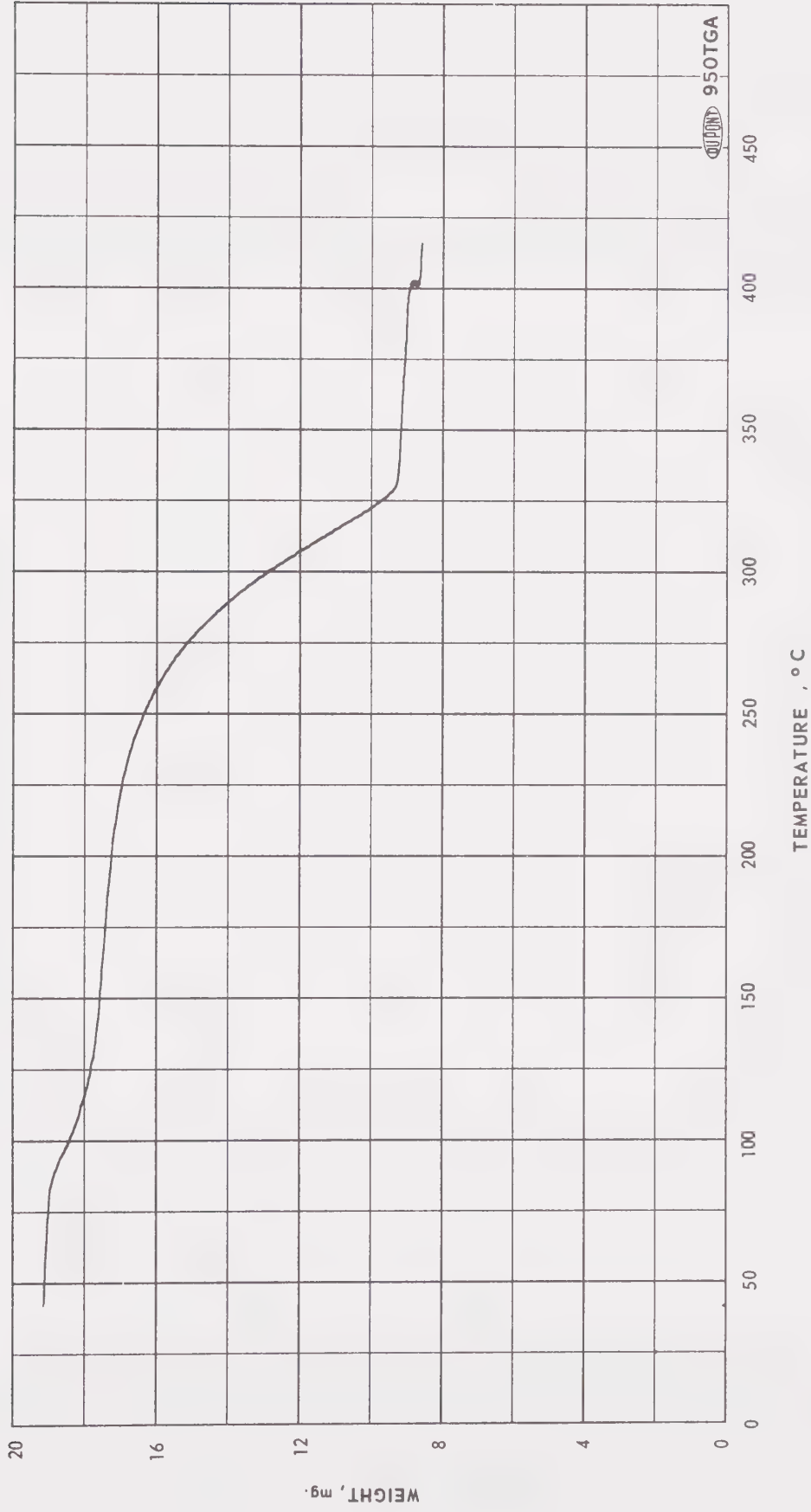


FIGURE 4: TYPICAL THERMAL GRAVIMETRIC ANALYSIS TRACE

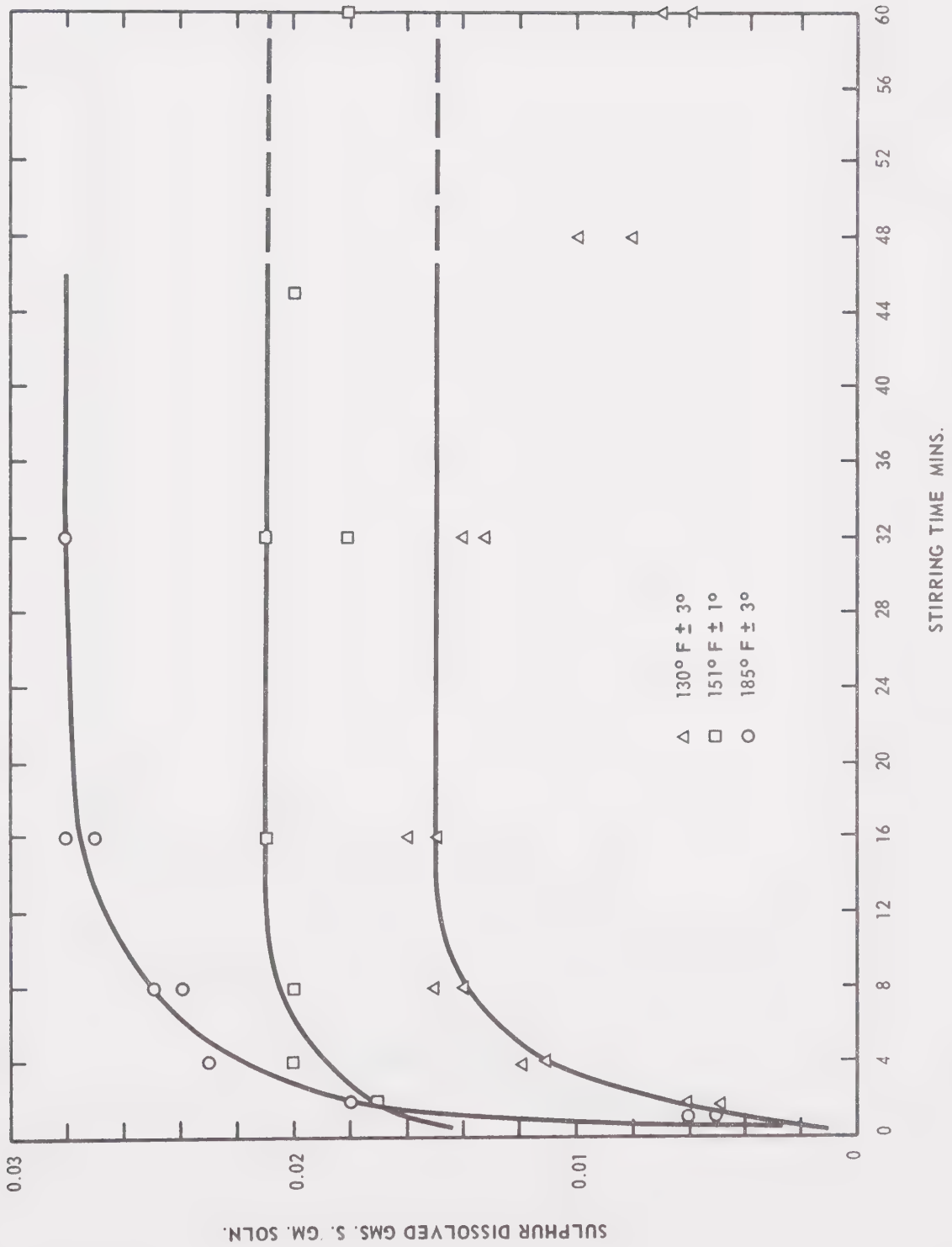


FIGURE 5: DISSOLUTION CHARACTERISTICS - SYNTHETIC ORE

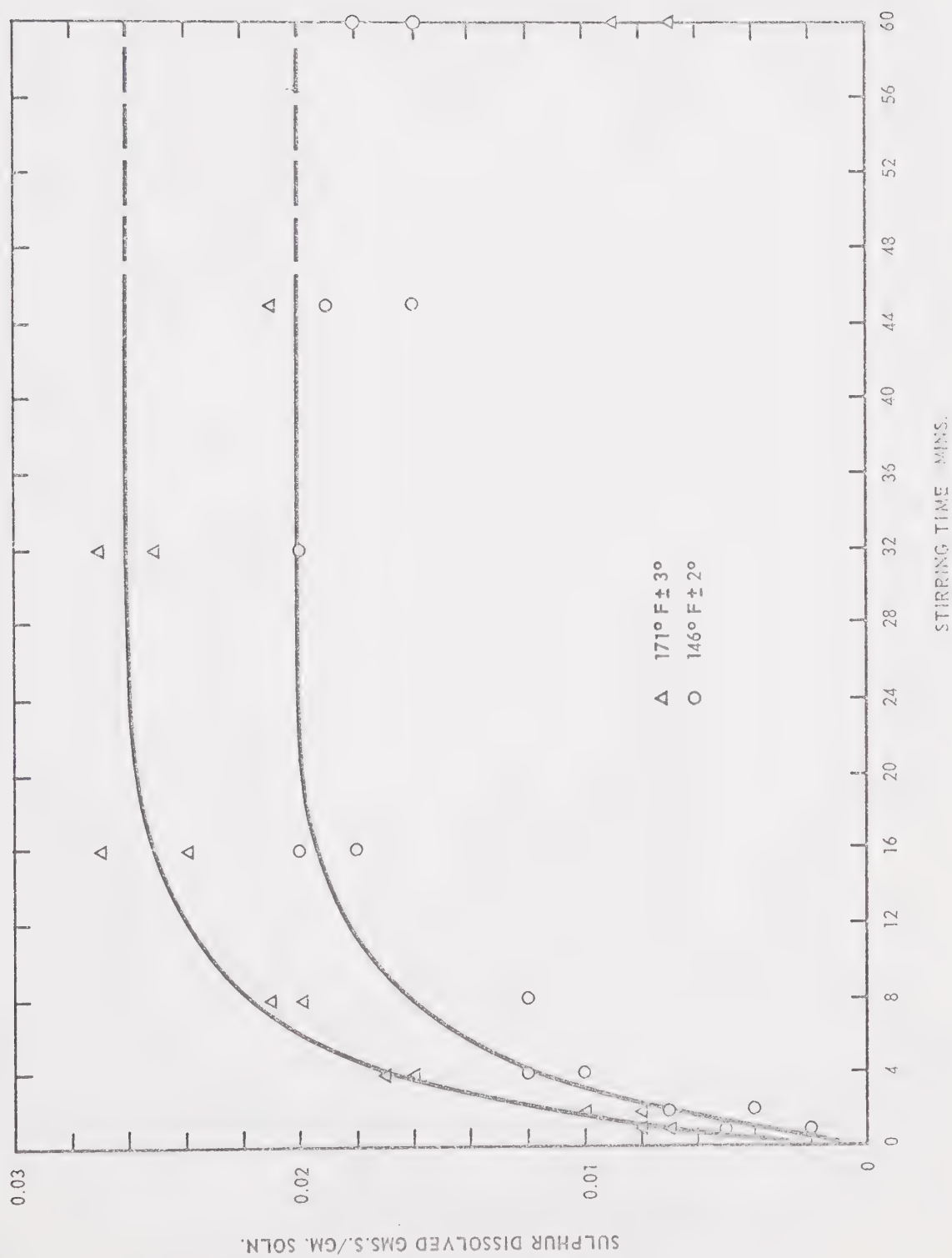


FIGURE 6: DISSOLUTION CHARACTERISTICS - SYNTHETIC ORE

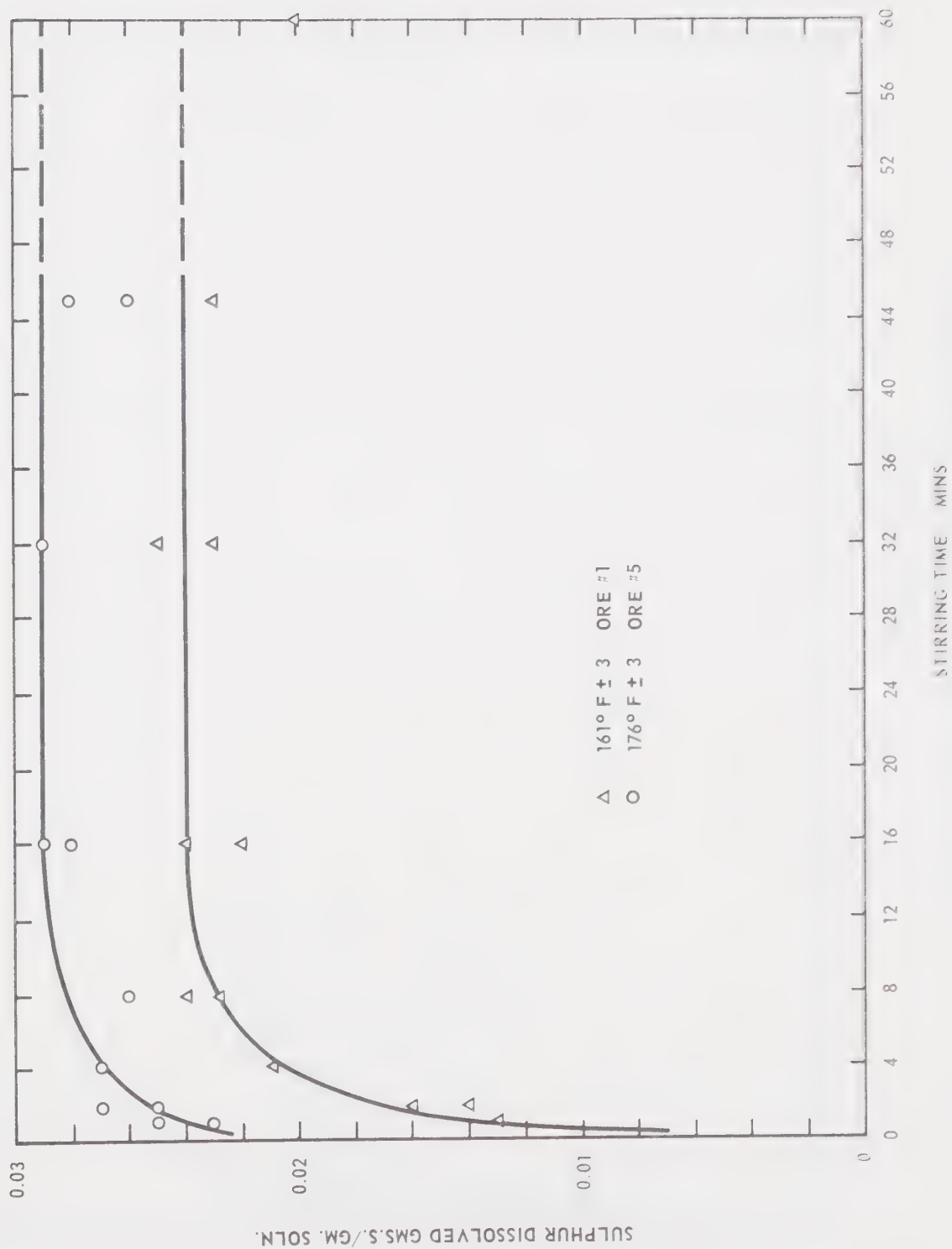


FIGURE 7: DISSOLUTION CHARACTERISTICS - ALBERTA ORES

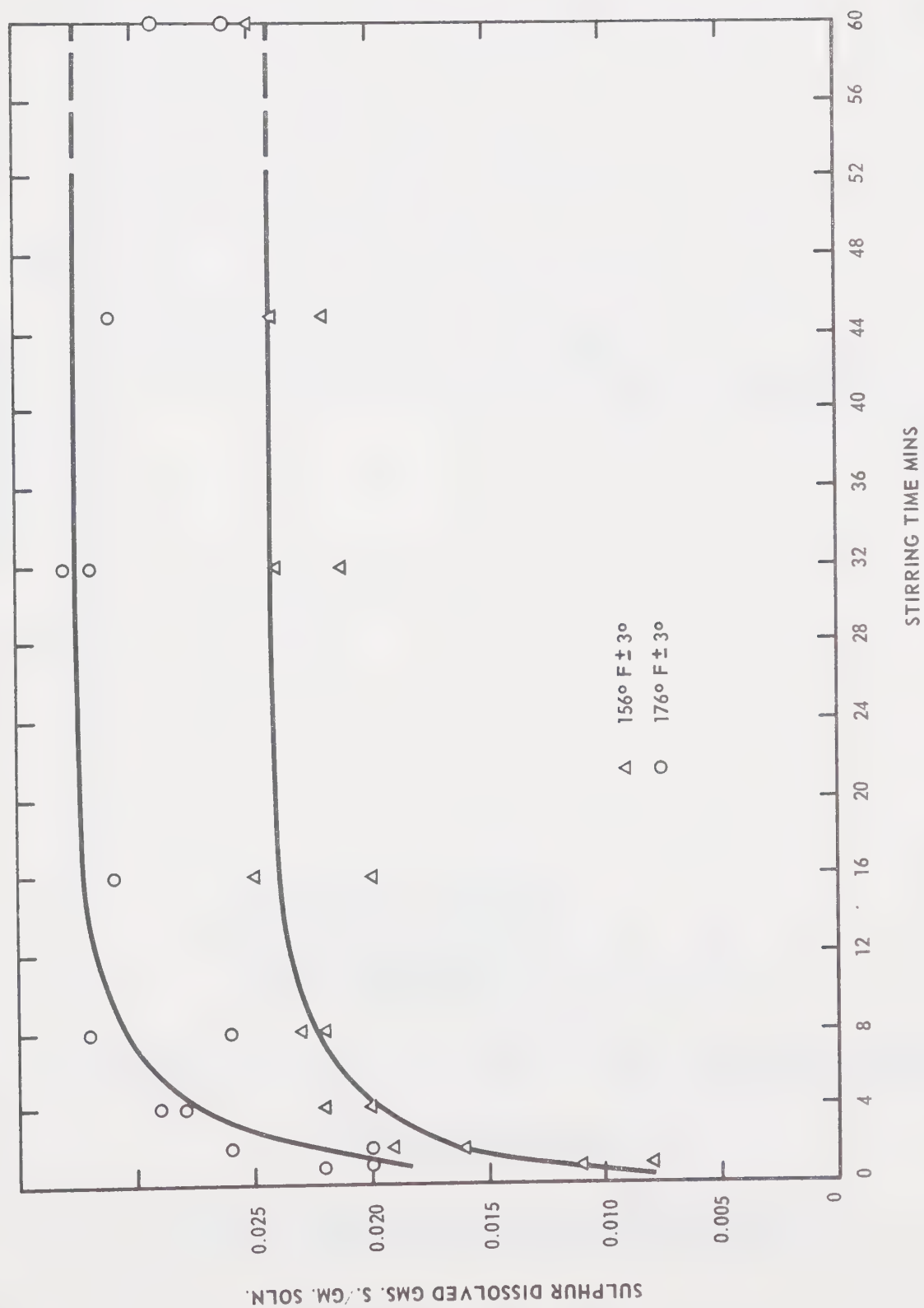


FIGURE 8: DISSOLUTION CHARACTERISTICS - ALBERTA ORE #5

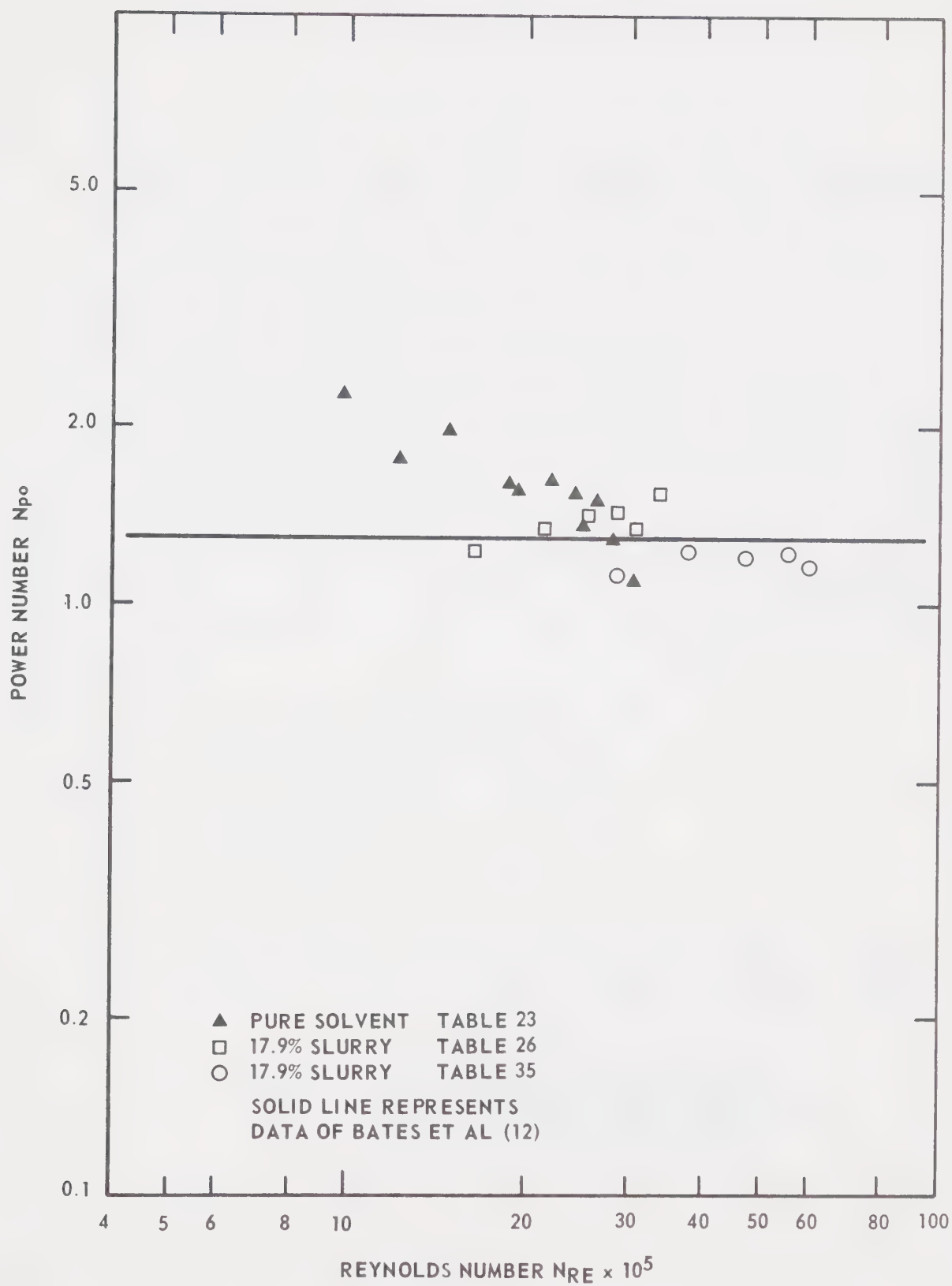


FIGURE 9: POWER NUMBER vs REYNOLDS NUMBER CURVE

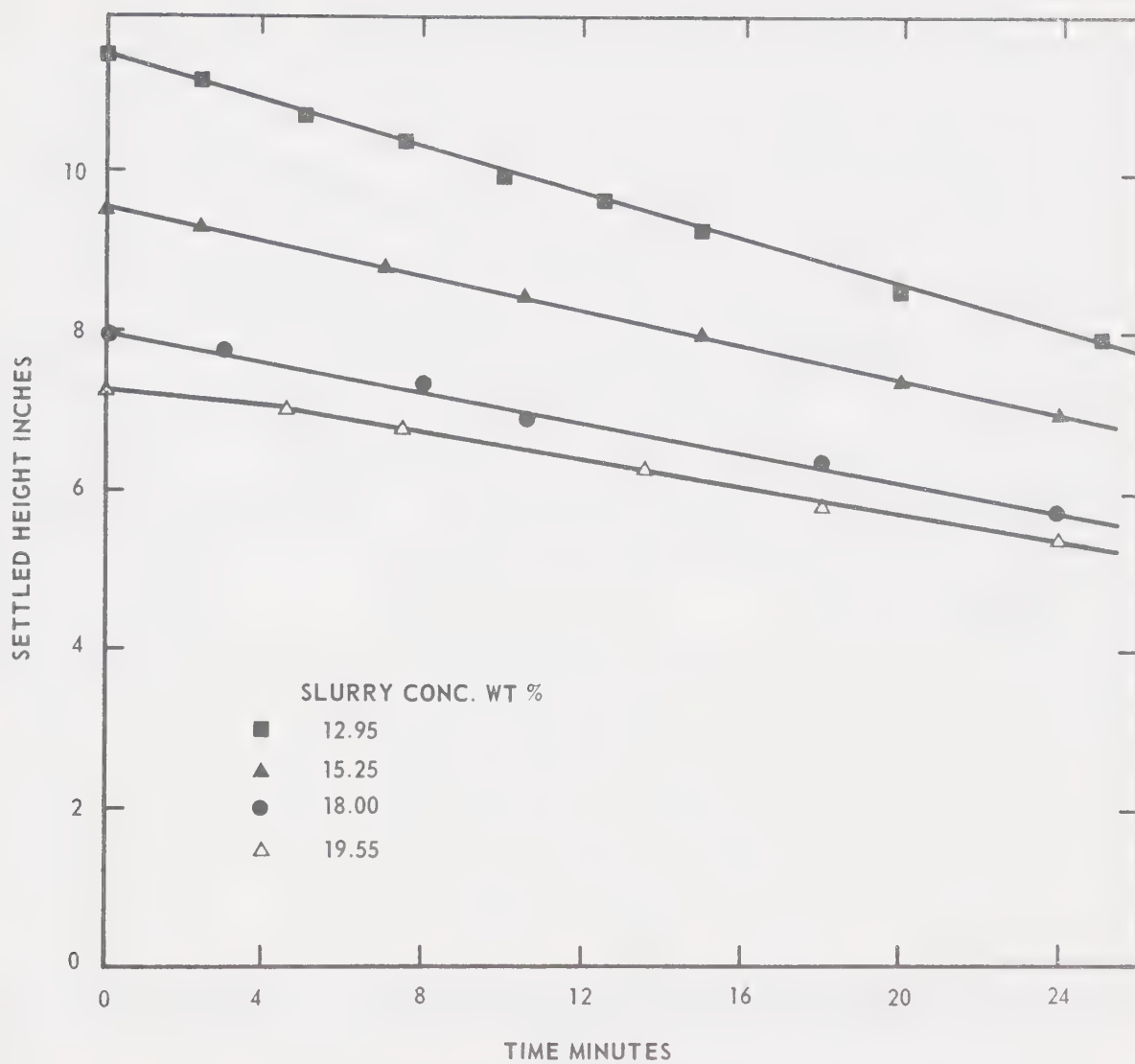


FIGURE 10: SEDIMENTATION CURVES FOR ALBERTA ORE TAILINGS WITHOUT ADDED CAUSTIC

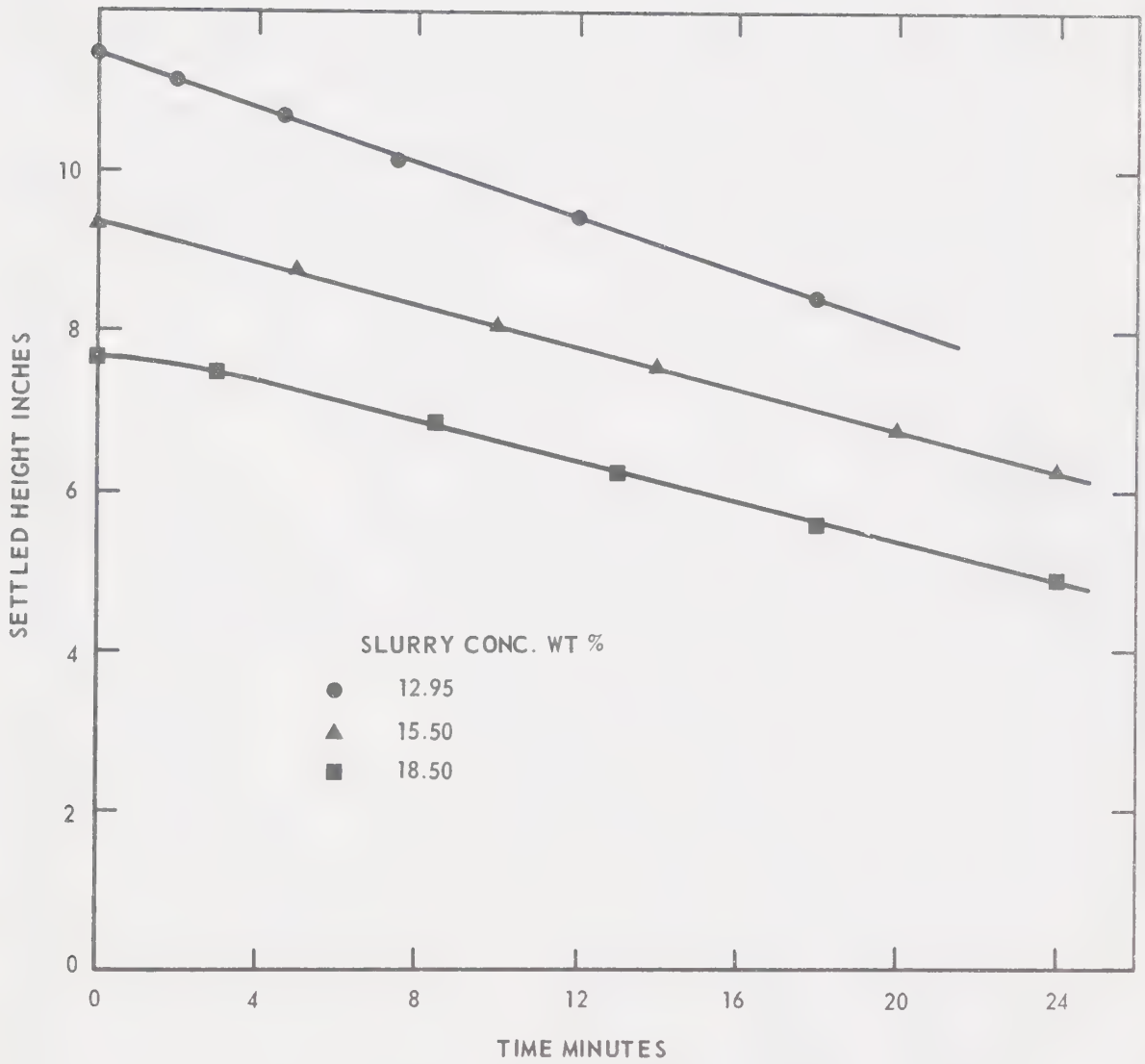


FIGURE 11: SEDIMENTATION CURVES FOR ALBERTA ORE TAILINGS WITH ADDED CAUSTIC

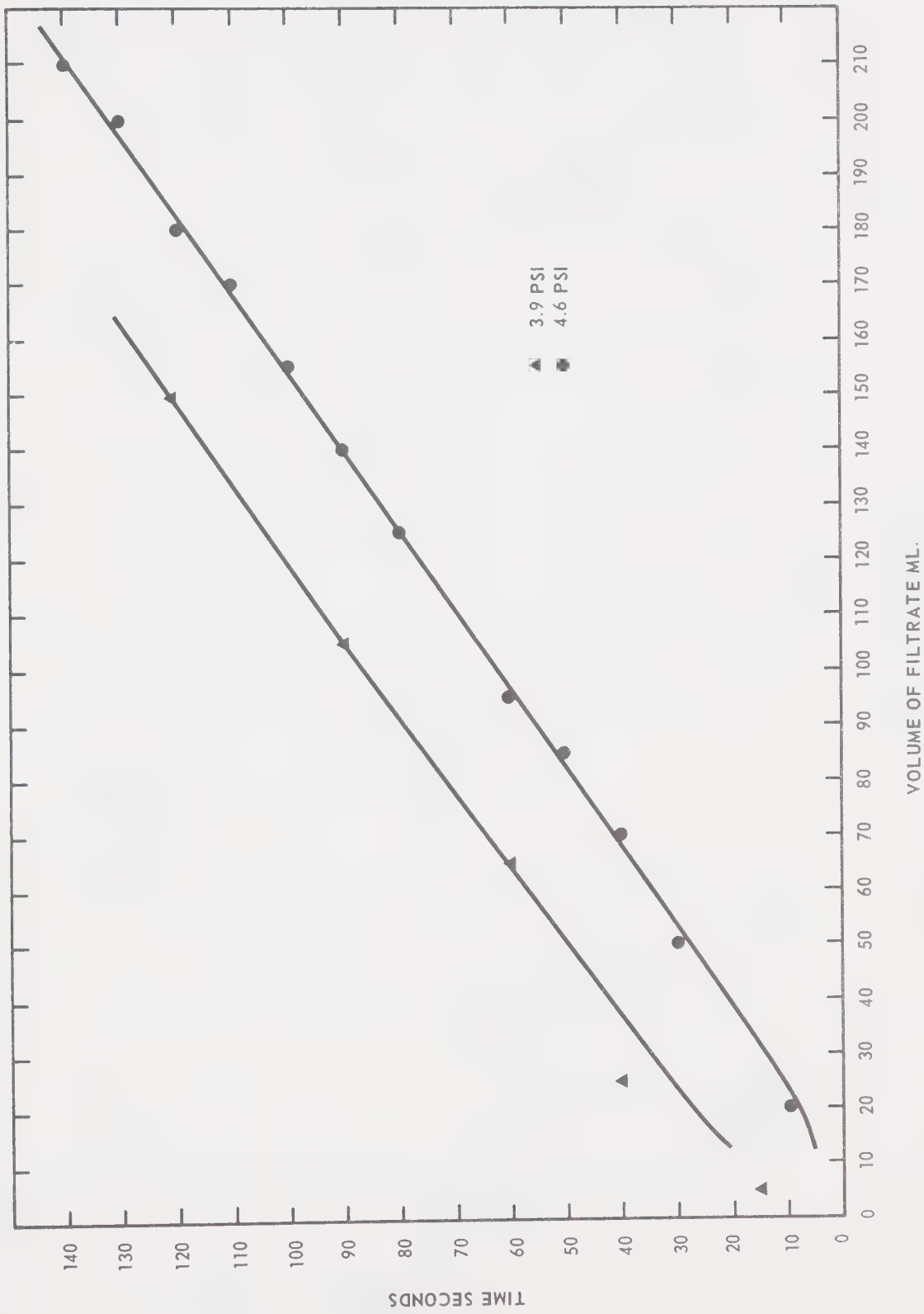


FIGURE 12: SULPHUR SLURRY FILTRATION CURVES

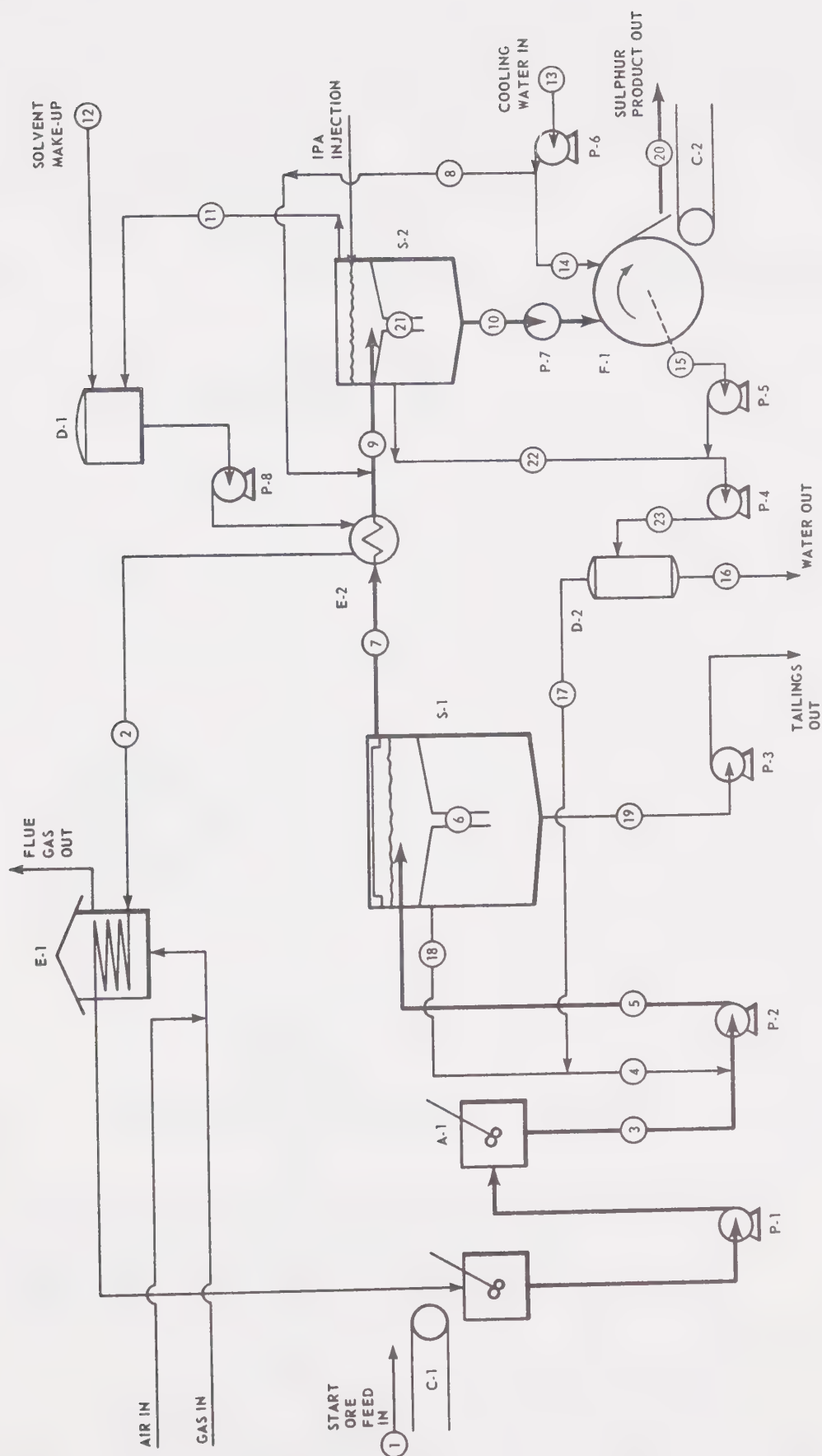
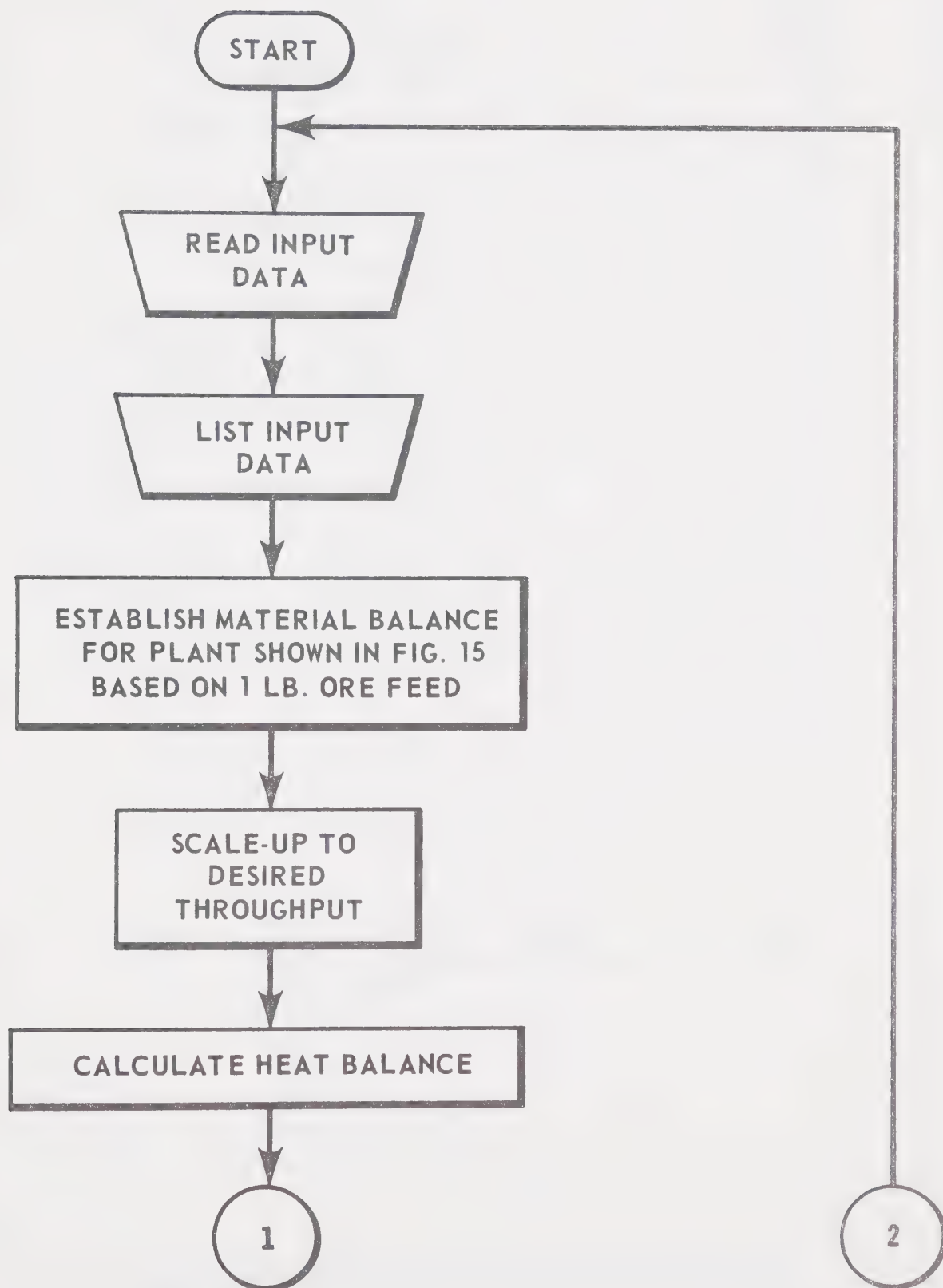


FIGURE 13: PROCESS FLOWSHEET



continued

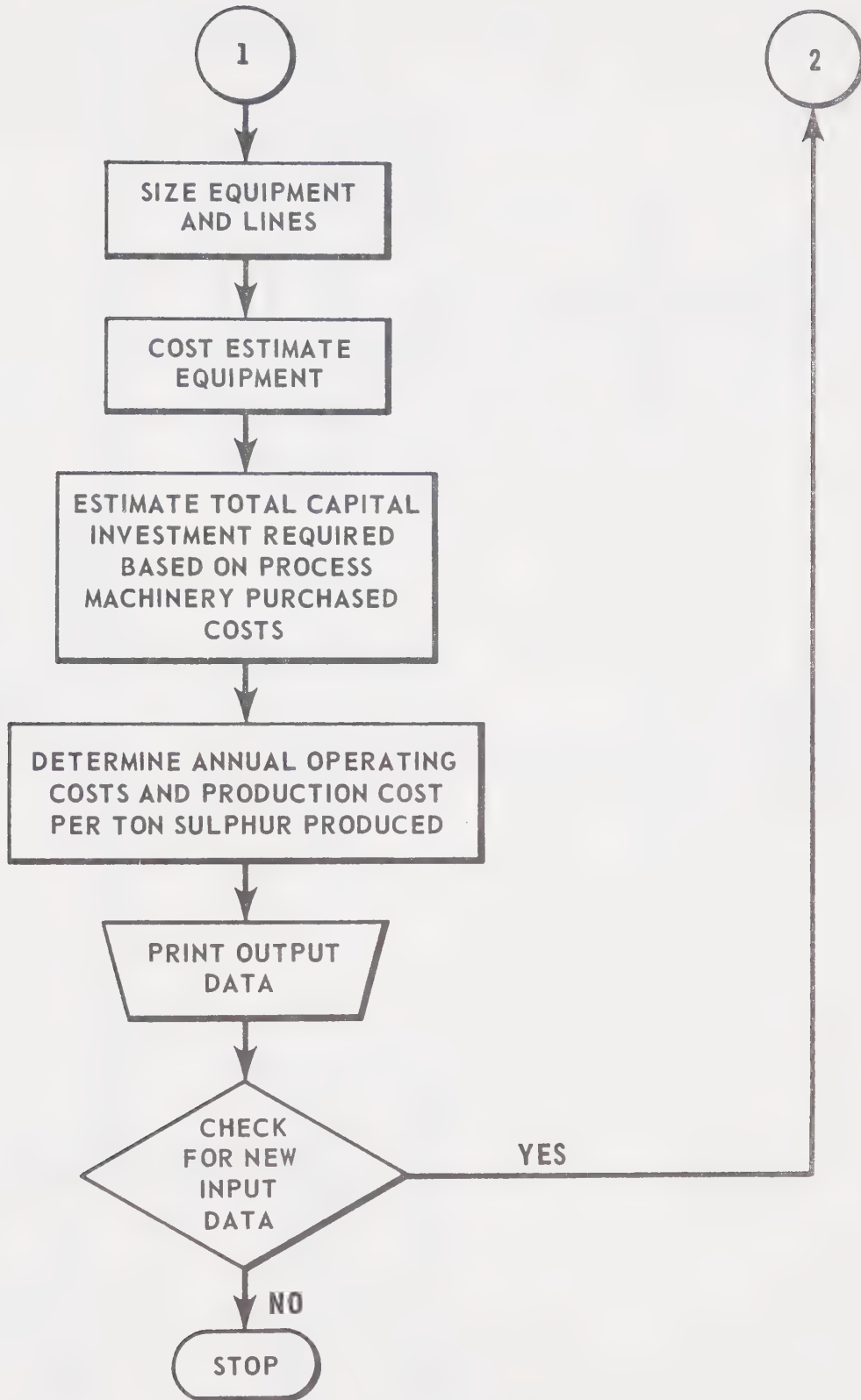


FIGURE 14: COMPUTER PLANT SIMULATION FLOWSHEET

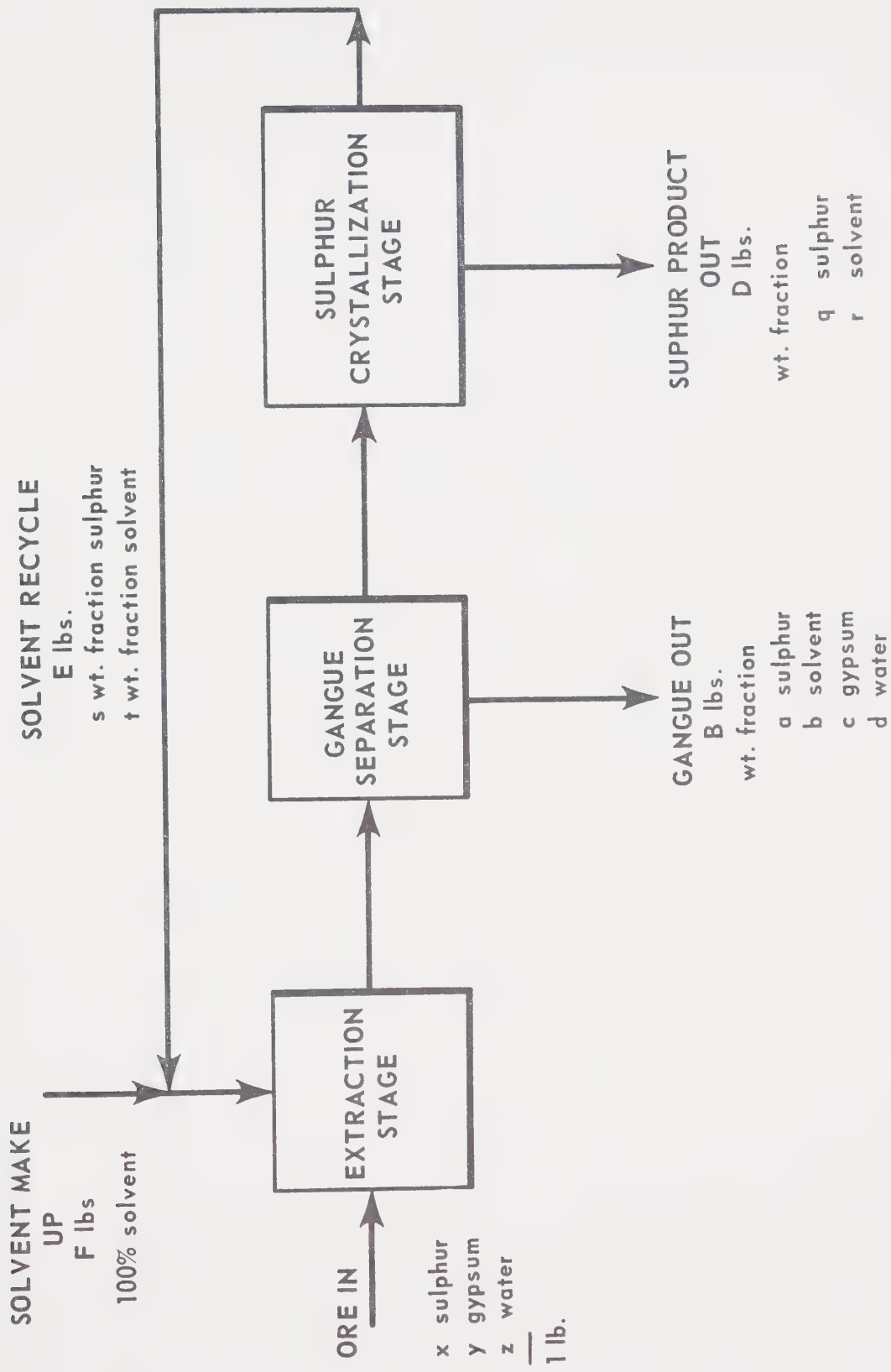


FIGURE 15: MATERIAL BALANCE BLOCK DIAGRAM FOR SOLVENT EXTRACTION PLANT

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